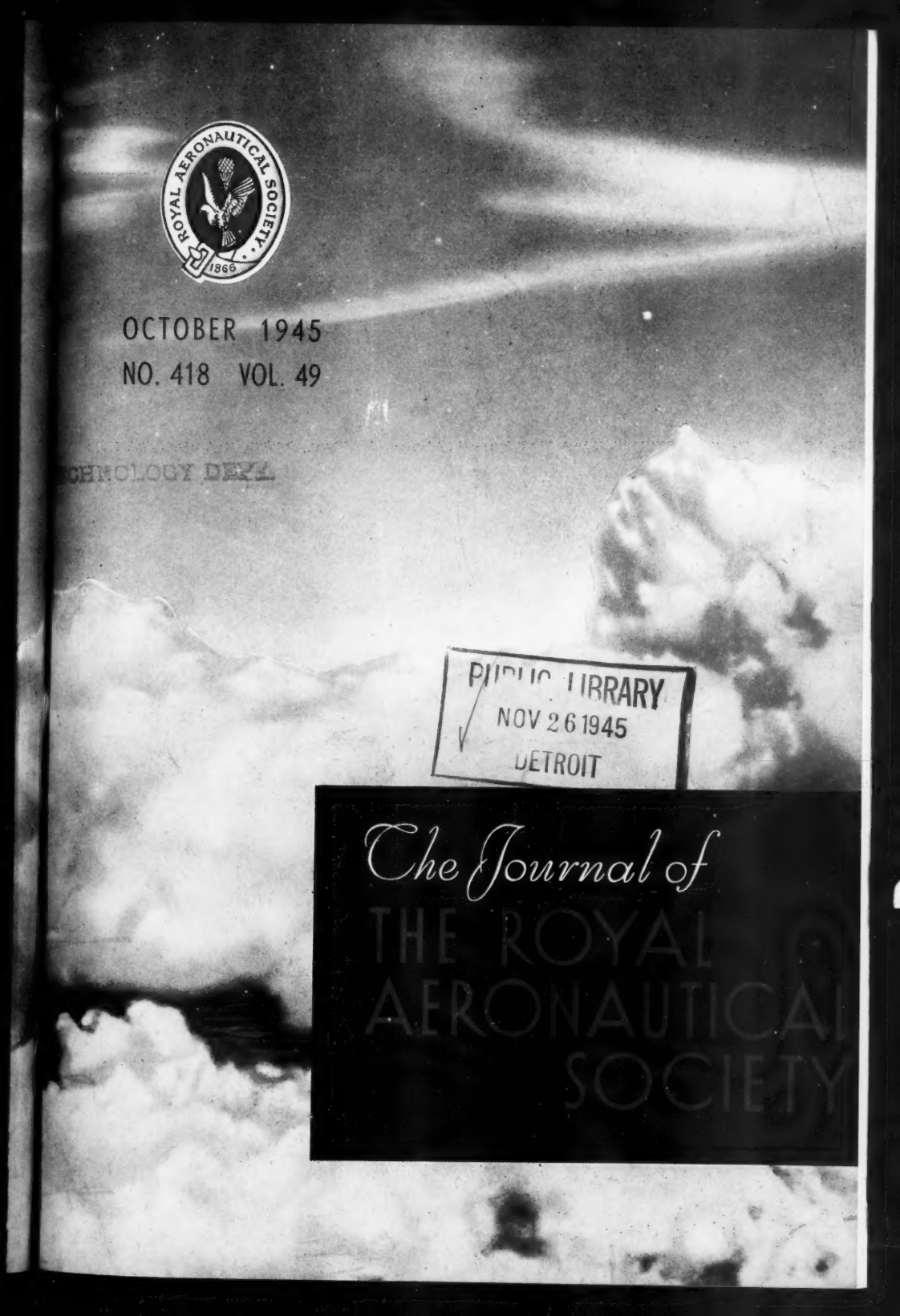
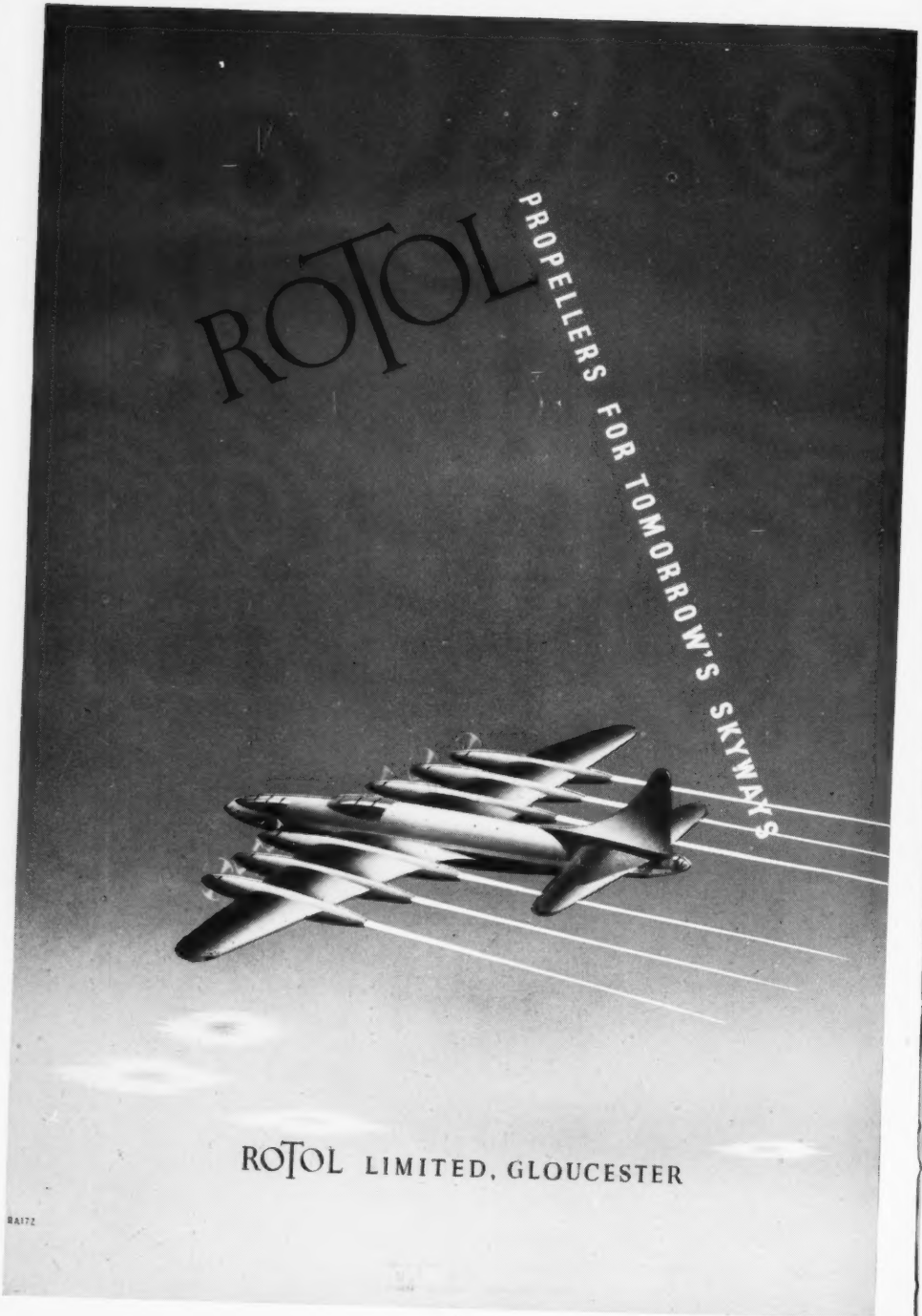


OCTOBER 1945
NO. 418 VOL. 49

CHNOLOGY DEPT.

PUBLIC LIBRARY
NOV 26 1945
DETROIT

The Journal of THE ROYAL AERONAUTICAL SOCIETY


ROTOL
PROPELLERS FOR TOMORROW'S SKYWAYS
ROTOL LIMITED, GLOUCESTER
BA172

Callender

AIRCRAFT CABLES

In to-day's operational aircraft no component carries higher responsibility for efficiency than electric cables.

Many types of cable—low tension, high tension and radio frequency—are acquired in modern installations and utmost reliability is the keynote of manufacture.

We make every type of cable needed for the electrical equipment of aircraft.

BRITISH INSULATED CALLENDER'S CABLES LIMITED

Main Works :

ERITH – HELSBY – LEIGH (Lancs) – PRESCOT

THEY WHO LOOK AHEAD

For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that would be;
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales.
Tennyson's "Locksley Hall"

Painted by W·James for

Helliwells Ltd.

PART OF BRITAIN'S AIRCRAFT INDUSTRY

HEAD OFFICE: OLD TOWN, STRATFORD-ON-AVON

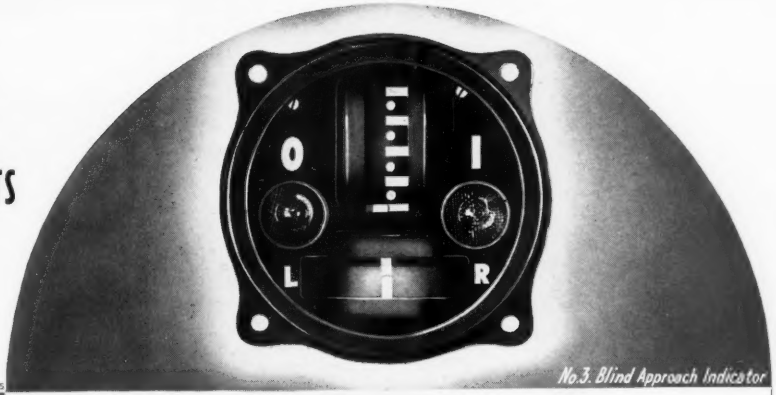
HALF A CENTURY OF KEEPING FAITH

ESTABLISHED 1889

FIFTY YEARS OF PROGRESS

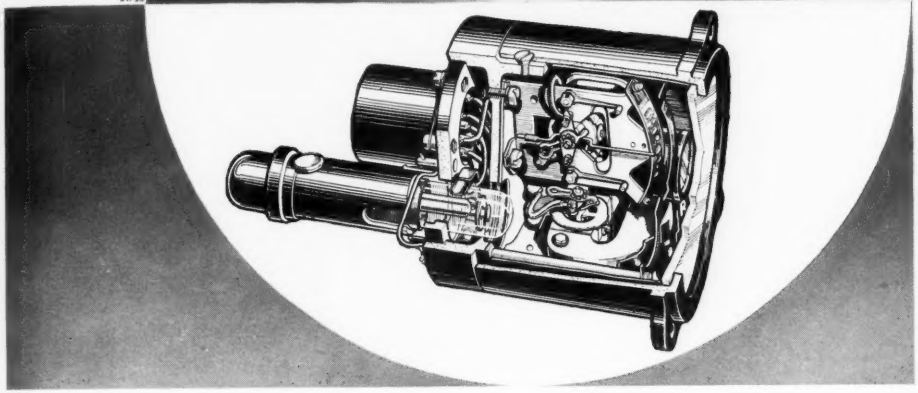
FUNGIMUR EIS QUAE PROMISIMUS

FEATURES OF WESTON AIRCRAFT INSTRUMENTS



SW35

No.3. Blind Approach Indicator



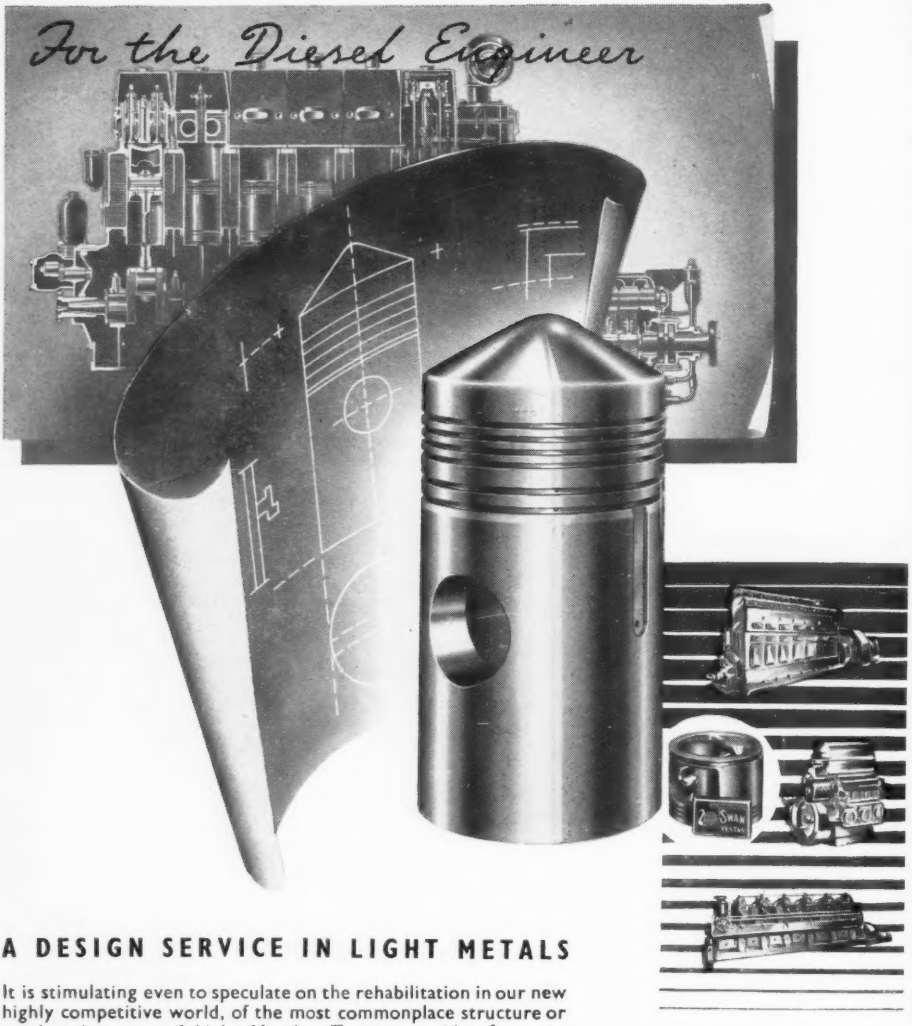
The Weston Blind Approach Indicator consists essentially of two standard Weston Moving Element assemblies, one placed horizontally and one vertically, receiving their impulse from a high frequency radio receiver. By its use the pilot is able to come in not only on the proper azimuth, but also at the correct angle of glide. Here again is seen the benefit of the rational design which has made possible the standardisation of the main instrument components, resulting in simplified production and maintenance and by the concentration of research, speeding the development of aids to navigation which cannot yet be publicised.

Weston AIRCRAFT INSTRUMENTS

☆ POSITIVE KNOWLEDGE FROM TAKE OFF TO TOUCH DOWN

SW34

SANGAMO WESTON LTD. ENFIELD MIDDLESEX



A DESIGN SERVICE IN LIGHT METALS

It is stimulating even to speculate on the rehabilitation in our new highly competitive world, of the most commonplace structure or product in terms of Light Metals. To give an idea form, to quicken the pace of attaining the full functional value of a mechanical product, Hiduminium Applications Ltd., *(designers to great organisations in the light metal industry)* invite manufacturers and others to share their experience and facilities in design and consultation. Further information on request.

HIDUMINIUM

APPLICATIONS LTD.

DESIGNERS IN LIGHT METALS FOR HIGH DUTY ALLOYS LTD.

REYNOLDS TUBE CO. LTD.
REYNOLDS ROLLING MILLS LTD.

FARNHAM ROAD SLOUGH BUCKS

THE SOCIETY'S AWARDS

The Society offers a number of valuable awards, most of them annually. Full particulars of the conditions attaching to these awards may be obtained on application to the Secretary.

Society's Gold Medal

This is the highest honour which the Society can confer for work of an outstanding or fundamental nature in aeronautics.

British Gold Medal for Aeronautics

The British Gold Medal for Aeronautics is awarded for an achievement leading to advancement in aeronautical science.

Simms Gold Medal

The Simms Gold Medal is awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, e.g., meteorology, wireless telegraphy, instruments.

The George Taylor (of Australia) Gold Medal

The Taylor Gold Medal is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

Wakefield Gold Medal

The Wakefield Gold Medal is awarded annually to the designer of any invention or apparatus tending towards safety in flying, and is open to members or non-members.

Society's Silver Medal

The Society's Silver Medal is awarded, at the discretion of the Council, for some advance in aeronautical design.

British Silver Medal for Aeronautics

The British Silver Medal for Aeronautics is awarded for an achievement leading to advancement in aeronautical science.

Society's Bronze Medal

The Society's Bronze Medal is awarded, at the discretion of the Council, under the same conditions as those for the Silver Medal, but for some less important advance in aeronautical design.

Wilbur Wright Memorial Premium

The Wilbur Wright Memorial Lecture is held annually, a premium of fifty pounds being awarded to the lecturer invited by the Council to deliver the lecture. The lecture is usually given alternately by an American and an Englishman, and is the most important aeronautical lecture of the year. It is delivered whenever possible, on the last Thursday in May of each year.

British Empire and Commonwealth Lecture

The Council of the Royal Aeronautical Society have completed the arrangements for the founding of a British Empire and Commonwealth Lecture.

The lecture, on any aeronautical subject approved by the Council, will be delivered annually in September in London, by a lecturer, chosen in alternate years from the British Dominions and Colonies and Great Britain.

The Council, by founding this British Empire and Commonwealth Lecture, are anxious to encourage new ideas and new points of view from all parts of the British Empire and Commonwealth, and to make the Lecture second only in importance to the Wilbur Wright Memorial Lecture.

The British Empire and Commonwealth Lecture will have a premium of £50 attached to it, and in the case of lecturers coming from the Dominions and Colonies an allowance up to £100 will be paid towards the Lecturer's expenses.

The first Lecture will be given on November 13th, 1945.

R.38 Memorial Prize

The R.38 Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in the science of aeronautics, preference being given to papers which relate to airships. The prize is twenty-five guineas.

The Herbert Akroyd Stuart Lectures

Under the will of the late Mr. Herbert Akroyd Stuart a sum of £700 is held in trust by the Society for the offer of a prize every two years, for the best paper or lecture read or given before the Society dealing with the Origin and Development of Heavy-oil Aero Engines. The prize is open to members and non-members.

Edward Busk Memorial Prize

The Edward Busk Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes (including seaplanes). Its value is twenty guineas.

Pilcher Memorial Prize

The Pilcher Memorial Prize is offered annually, at the discretion of the Council, for the best paper by a Student on heavier-than-air craft or any analogous subject. Its value is five guineas.

Usborne Prize

The Usborne Prize is offered annually, at the discretion of the Council, for the best paper by a Student on some subject in connection with Aero Engines. Its value is five guineas.

Major Baden-Powell Memorial Prize

The Major Baden-Powell Memorial Prize is awarded in May and December of each year to the student who is considered the best student by the examiners in the Society's Association Fellowship examinations. Its value is three guineas.

Elliott Memorial Prize

The Elliott Memorial Prize is awarded twice yearly to the apprentice at Halton who has the highest percentage of marks in the passing-out examination. Its value is 2½ guineas for each award.

R. P. Alston Memorial Prize

The R. P. Alston Memorial Prize is awarded to any Graduate or Student of the Society for work done leading to improvement in the safety of aircraft, and particularly for improvement in stability and control. Its value is approximately £5.

Branch Prize

The Council offer an annual prize of twenty guineas for the best paper read before the Branches during the previous lecture Session. The prize is open to any member of the Society or of any Branch.

Journal Premium Awards

The Council has set aside an annual sum of £250 to be given as premium awards to authors of papers published in the Journal.

AN APPRECIATION

The Council of the Royal Aeronautical Society wish to thank those Companies who, by their generous co-operation, have done so much to help in the production of the Journal in its new form.

ACCLES & POLLOCK LTD

A&P
Make it with Tubes

AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.

ALUMINIUM CASTINGS

AC-SPHINX SPARKING PLUG CO., LTD.

AC
MADE IN ENGLAND

AIRCRAFT PRODUCTION

AIRCRAFT PRODUCTION
AN ASSOCIATED ILIFFE PUBLICATION

AERASPRAY MFG. CO., LTD.

AERASPRAY

AIRSPEED LIMITED

AIRSPEED

"THE AEROPLANE"

THE AEROPLANE
TEMPLE PRESS Ltd.

ALVIS LIMITED

ALVIS

GEORGE ANGUS & CO., LTD.

OIL GACO SEALS

AVIMO LIMITED

AVIMO

OPTICAL - MECHANICAL - ELECTRICAL INSTRUMENTS
AERONAUTICAL EQUIPMENT

ARMSTRONG SIDDELEY MOTORS LIMITED

ARMSTRONG SIDDELEY

BAKELITE LIMITED

TREFOIL
BAKELITE PLASTICS
REGD. TRADE MARKS

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.

SIR W. G.
ARMSTRONG WHITWORTH
AIRCRAFT LIMITED

BECKETT, LAYCOCK AND WATKINSON, LTD.

REGD. TRADE MARK
BECLAWAT

THE AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO., LTD.

AVO

ELECTRICAL
TESTING
INSTRUMENTS

T. M. BIRKETT & SONS LTD.

BIRSO
TRADE MARK
NON-FERROUS CASTINGS
AND MACHINED PARTS
HANLEY - - STAFFS

AUTOMOTIVE PRODUCTS COMPANY LTD.

HIGH PRECISION HYDRAULICS
Lockheed

BLACKBURN AIRCRAFT LTD.

Blackburn
AIRCRAFT

JAMES BOOTH & COMPANY LIMITED

STRONG LIGHT ALUMINIUM ALLOYS **DURALUMIN**

REGD. TRADE MARK

BRITISH ERMETO CORPORATION LTD

ERMETO

BOULTON PAUL AIRCRAFT LTD.

AIRCRAFT & BPA ARMAMENTS

THE BRITISH PARACHUTE COMPANY LIMITED

Y DRAIG GOCH A DDERY GYCHWYN

THE BRISTOL AEROPLANE CO., LTD.

"Bristol"

BRITISH PLASTICS

British Plastics

AN ASSOCIATED ILIFFE PUBLICATION

THE BRITISH ALUMINIUM CO., LTD.

BA

BRITISH ROPES LIMITED

BRITISH ROPES LIMITED BR

HEAD OFFICE: DONCASTER

THE BRITISH AVIATION INSURANCE COMPANY LTD

BA IC

BRITISH THOMSON-HOUSTON CO., LIMITED (THE)

B T-H

Magnetos and Electrical Equipment

BRITISH WIRE PRODUCTS LTD.

DAVID BROWN & SONS (HUDDERSFIELD) LTD.

David Brown

THE BROCKHOUSE ORGANIZATION

BROCKHOUSE

THE BUSHING COMPANY LIMITED

THE BROOKE TOOL MANUFACTURING CO., LIMITED

DESIGNERS & MANUFACTURERS
OF
JIGS AND FIXTURES
AIRCRAFT COMPONENTS
ENGINEERS' SMALL TOOLS

BUTLERS LIMITED

AUTOMOBILE, AIRCRAFT AND MARITIME LAMPS
SEARCHLIGHTS AND MOTOR ACCESSORIES

BROOM & WADE LTD.

"BROOMWADE"

CALLENDER'S CABLE & CONSTRUCTION CO., LTD.

Callender CABLES
FOR EVERY ELECTRICAL PURPOSE

BROWN BROTHERS (AIRCRAFT) LTD.

Brown Brothers (AIRCRAFT) Ltd.
CONTROLS AEROJACK & A.G.S. & A.S. PARTS

CHARLES CHURCHILL & CO., LTD.

CHURCHILL
Machine Tools
and Equipment

THE CHLORIDE ELECTRICAL STORAGE CO. LTD.

Exide
AIRCRAFT BATTERIES

DOWTY EQUIPMENT LIMITED

DOWTY
UNDERCARRIAGE AND
HYDRAULIC EQUIPMENT

COOPER & CO. (B'HAM), LIMITED

COOPERS
INDUSTRIAL FELT PRODUCTS

DUNFORD & ELLIOTT (SHEFFIELD) LTD.

Dunelt
Special steels
FOR AIRCRAFT

CROWN WELDING CO., LTD.

CROWN WELDING
DOUGLAS

DUNLOP RUBBER CO., LTD.

DUNLOP

THE DE HAVILLAND AIRCRAFT
COMPANY LIMITED

DH

ENGLISH STEEL CORPORATION LTD.

STEEL MANUFACTURERS
ESC
ENGLISH STEEL
CORPORATION LTD
SHEFFIELD

DELCO-REMY & HYATT LTD.

ELECTRIC
Delco
MOTORS

THE FAIREY AVIATION COMPANY LTD.

FAIREY
HIGH-PERFORMANCE SERVICE AIRCRAFT

FERODO LIMITED

FERODO
REGD. TRADE MARK
BRAKE & CLUTCH LININGS

FOLLAND AIRCRAFT LTD.

FOLLAND AIRCRAFT LTD
HAMBLE, SOUTHAMPTON

THOS. FIRTH & JOHN BROWN LTD.

STEEL STEEL STEEL STEEL STEEL
STEEL STEEL STEEL STEEL STEEL
STEEL FIRTH-BROWN STEEL
STEEL STEEL
STEEL STEEL STEEL STEEL STEEL
STEEL STEEL STEEL STEEL STEEL
THOS FIRTH & JOHN BROWN LTD SHEFFIELD

GENERAL AIRCRAFT, LTD.

GENERAL AIRCRAFT LTD

FIRTH-VICKERS STAINLESS STEELS LTD.

"Staybrite" FV

GILLETT STEPHEN & CO., LTD.

GS

MANUFACTURERS OF UNDERCARRIAGES AND HYDRAULICS FOR AIRCRAFT

FLIGHT PUBLISHING CO., LIMITED

FLIGHT and AIRCRAFT ENGINEER
AN ASSOCIATED ILIFFE PUBLICATION

GIRLING LIMITED

GIRLING
The Best Brakes in the World

FLIGHT REFUELLING LTD.

FLIGHT REFUELLING

GLOSTER AIRCRAFT CO. LTD.

GLOSTER AIRCRAFT CO. LTD.

GRAVINER MANUFACTURING COMPANY LTD.

REG° TRADE MARK
GRAVINER
MANUFACTURING COMPANY LTD.

THE HESTON AIRCRAFT CO., LTD.

HESTON AIRCRAFT

HANDLEY PAGE LTD.

HP

THE HEYWOOD COMPRESSOR CO. LTD.

Hymatic

COMPRESSED AIR EQUIPMENT

HAWKER AIRCRAFT LTD.

HAWKER

HIDUMINIUM APPLICATIONS LTD.

HDA TI

HEALTHGUARD AEROQUIPMENT

HIGH DUTY ALLOYS LTD.

HDA

HELLIWELLS LTD.

HALF A CENTURY OF KEEPING FAITH
1889
FIFTY YEARS OF PROGRESS

H. M. HOBSON (AIRCRAFT AND MOTOR) COMPONENTS LTD.

Hobson

S. HUBBARD LIMITED

MECHOFELT
HUBBARD MECHANICAL FELT

IMPERIAL CHEMICAL INDUSTRIES LIMITED

ICI

F. A. HUGHES & CO., LIMITED

Distributors of
ELEKTRON
MAGNESIUM ALLOYS

INTEGRAL LTD.

INTEGRAL

HENRY HUGHES & SON LTD.

HUSUN

IRVING AIR CHUTE OF GREAT BRITAIN LTD

AIR CHUTES
IRVIN

THE HUGHES-JOHNSON STAMPINGS LTD

JABLO PROPELLERS, LIMITED

JABLO
PROPELLER BLADES

HUNTING AVIATION LIMITED
(formerly Necaco Ltd.)

HUNTING

WALTER W. JENKINS & CO., LTD.

WALTER W. JENKINS AND COMPANY LIMITED

MANUFACTURERS OF HYDRAULIC AND ELECTRICAL EQUIPMENT

K.D.G. INSTRUMENTS LTD.

LEYTONSTONE JIG & TOOL CO., LTD.

KELVIN BOTTOMLEY & BAIRD LTD.

LIGHT-METAL FORGINGS LTD.

K.L.G. SPARKING PLUGS LTD.

LODGE PLUGS LIMITED

LANGLEY ALLOYS LTD.

THE LONDON NAME PLATE MANUFACTURING CO., LTD.

ARTHUR LEE & SONS, LTD.

MAGNESIUM CASTINGS & PRODUCTS LTD.

THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY

With which is incorporated The Institution of Aeronautical Engineers

CONTENTS — *OCTOBER, 1945*

NOTICES .. .. 611—615

ESTIMATION OF STATIC LONGITUDINAL STABILITY
By E. J. N. Archbold, B.Sc. (Eng.), Grad.R.Ae.S., Tech.M.I.Ae.S. 616—638

EULER CRITICAL LOAD OF PINNED-PINNED 'POLYNOMIAL' TAPERED STRUTS
By F. J. Turton, B.Sc., A R.C.S. .. 639—645

STRESSES IN RING STRUCTURES
By L. G. Whitehead, Ph.D. .. 646—651

RETARDATION EFFICIENCY OF SHOCK-ABSORBER AND ARRESTER GEAR
By P. B. Walker, M.A., Ph.D. .. 652—657

REVIEW 658

THE SOCIETY'S PRIZES .. .. vii—viii

DIRECTORY OF ADVERTISERS xxvi—xxx

The Journal of The Royal Aeronautical Society was founded in 1897 in succession to the Annual Reports. For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. **The Journal is published monthly at the Offices of the Society, 4, Hamilton Place, Piccadilly, London, W.1.** Subscriptions per annum, £4 13 0 including postage; Single Numbers 7/6 or 7/9 post free. All communications for publication in the Journal, or on general matters affecting the Society should be addressed to — The Secretary, J. Laurence Pritchard, 4, Hamilton Place, W.1. The Society's Bankers are Messrs. Coutts and Co. All communications respecting Advertisement matters should be addressed to—The Advertisement Manager, Journal of The Royal Aeronautical Society, 4, Hamilton Place, W.1.
Telephone: Grosvenor 3515-3516-3517. Telegraphic Address: Didaskolas, Audley, London.

OCTOBER NOTICES 1945

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

An Appeal to Members

The Society is very anxious to have as complete a record as possible in its files of the work of its members. Such a record will enable the Society to be of greater use to its members and to know, particularly, those members who can help the Council and its Committees on problems which are under discussion.

It would be appreciated, therefore, if members would bring their records of work and employment up to date; and in future notify headquarters of any change of job or position on a firm. In most cases the records held by the Society do not go beyond the date of election as Fellow, Associate Fellow or Associate, and often, therefore, are some years out of date.

The Council are forming a number of technical committees and are anxious to draw upon the best talent among its members in order that the most authoritative reports may be presented.

Contents of the October Journal

Estimation of Static Longitudinal Stability, by E. J. N. Archbold, B.Sc.(Eng.), Grad.R.Ae.S., Tech.M.I.Ae.S.

Euler Critical Load of Pinned-Pinned "Polynomial" Tapered Struts, by F. J. Turton, B.Sc., A.R.C.S.

Stresses in Ring Structures, by L. G. Whitehead, Ph. D.

Retardation Efficiency of Shock-Absorber and Arrester Gear, by P. B. Walker, M.A., Ph.D., F.R.Ae.S.

List of Members

A List of Members is in active preparation. Will members therefore send in any changes in their addresses and designations? If a member has more than one address an indication should be given of the one to appear in the printed list. If no notification is received it will be assumed that the titles and address on the Journal envelope or Monthly Notices are correct.

Lecture Programme

The following are the forthcoming Lectures of the first half of the 1945-1946 Lecture Session. Members are admitted without tickets, but non-members must obtain tickets through a member.

The Lectures will be held at 6.30 p.m. in the Lecture Theatre of the Institution of Mechanical Engineers, Storey's Gate, St. James's, S.W.1 (by permission of the Council of the Institution), with the exception of the British Commonwealth and Empire Lecture, and the lecture by Professor Feather.

October 18th—Aircraft Engine Oil Cooling, by Mr. F. Nixon, B.Sc., M.I.Aut.E., F.R.Ae.S.

November 1st—A Critical Review of German Long-range Rocket Development, Mr. W. G. A. Perring, F.R.Ae.S.

November 29th—Aspects of German Aeronautical Development, by W. J. Stern, B.Sc.

December 11th—Meteorology and High Altitude Aviation, by Professor Dobson, F.R.S.

November 13th—The First British Commonwealth and Empire Lecture. Australia in Empire Air Transport, by W. Hudson Fysh, D.F.C.

The lecture will be held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. (Tea 6.0 p.m.)

December 19th—Atomic Disintegration, by Professor N. Feather, F.R.S.

The lecture will be delivered in the Institution of Civil Engineers, Great George Street, S.W.1, at 6.0 p.m. (Tea 5.30 p.m.)

Branch Lectures

BIRMINGHAM BRANCH

October 22nd—Annual General Meeting at the White Horse Hotel, Congreve Street, Birmingham, at 6.45 p.m.

October 29th—The Principles of Radar, by Mr. D. R. Davies, B.Sc., A.M.I.E.E., and Mr. H. Turner. The lecture will be illustrated with films and will be held at the Chamber of Commerce, 95, New Street, Birmingham.

COVENTRY BRANCH

November 22nd—Modern Experimental Work in Aircraft Structures, by Professor A. G. Pugsley, F.R.Ae.S.

Lectures will be held in the Council Staff Canteen, Old Gulson Library, at 7 p.m.

DERBY BRANCH

Lectures by the following have been arranged and will be held in the Rolls-Royce Welfare Hall, Nightingale Road, Derby:—

November 5th—Air Commodore Vernon Brown, C.B., O.B.E., M.A., F.R.Ae.S., and Wing Commander N. G. Bennett, M.B.E. (Air Ministry Accidents Investigation Branch).

December 3rd—Annual General Meeting.

GLASGOW BRANCH

November 15th—Fuel Injection, by Mr. Morris.

Meetings will be held in the Royal Technical College, George Street, Glasgow, at 7.30 p.m.

LUTON BRANCH

November 7th—Electrics for Aircraft, by C. G. A. Woodford, A.F.R.Ae.S.

November 21st—Rubber Bonding Applications, by Messrs. Reynolds and Buchan (Andre Rubber Co., Ltd.) and Mr. Moore (Silentbloc).

Lecture are held in The George Hotel at 7.15 p.m.

BELFAST BRANCH

October 30th—Jet Propulsion for Aircraft, by H. G. Winton, A.F.R.Ae.S.

November 20th—Aircraft Electrical Installations, by G. A. Coombes, A.R.Ae.S.

December 11th—Modern Development in Aircraft Performance, by C. P. T. Lipscombe, WH.Ex., F.R.Ae.S. (Joint Lecture with the Belfast Association of Engineers.)

Graduate and Student Section

Thursday, October 25th—Production of Cold Rolled Sections for Aircraft, by N. Aston, M.J.I.E. (Hawker Aircraft).

November (exact date to be fixed)—German Aeronautical Research, by F/L. J. R. Ewans (R.A.E. Team in Germany).

Tuesday, November 27th—Large Wooden Aircraft, by J. K. Crowe, A.F.R.Ae.S. (De Havilland Aircraft).

Friday, December 7th—Steel. Film show by courtesy of John Brown & Co. 6.0 p.m. British Council Theatre, 6, Hanover Street, W.1. Refreshments available from 5.30.

All meetings will be held in the Library of the Society at 4, Hamilton Place, W.1, at 7.30 p.m., unless otherwise stated.

NOTICES

Presentation of Photographs

The Council acknowledge with thanks the gift of photographs of their machines from the following firms:—

Blackburn Aircraft, Ltd., Bristol Aeroplane Co., Ltd., De Havilland Aircraft Co., Ltd., De Havilland Engine Co., Ltd., Fairey Aviation Co., Ltd., Gloster Aircraft Co., Ltd., Handley Page, Ltd., Hawker Aircraft, Ltd., Miles Aircraft, Ltd., D. Napier & Son, Ltd., Rolls-Royce, Ltd.

These photographs are of very great value to the records of the Society and help to keep the files up to date. Members interested may consult the files at any time. The Council will be grateful for photographs of any aircraft, during construction or in flight, especially those covering the years 1907 to 1914.

Election of Members

The following members were recently elected:—

Associate Fellows

Norman William George Blackburn, Robert Peter Bonnell, David Brown, Herbert George Frederick Butler, John Caldwell, Zbyslaw Ciolkosz, Edmund William Coates (from Graduate), Andrew William Crichton (from Student), Donald Merewood Hallowes, Henry Richard Haynes, Ronald Hills, Stanley Steele Holman (from Graduate), Robert Henry Horniman, Bruno Jablonsky, John Owen Napier Lawrence, James Millar Logie, Zdzislaw Teofil Marczewski, Charles Henry Naylor (ex - Student), Alexander Robert Ogston, Antoni Kazimie Oppenheim, Leonard Arthur Pollard, John Maurice Radcliffe, Elfyn John Richards, Laszlo Rossz, William Godfrey Meyer Sanders, Richard Ewell Smith, Stefan Smoleniec, Thomas Alfred Stanley (from Graduate), Frank Edmund Stokes, James Douglas Sumner, Frederick George Tarrant, Percival John Taylor (from Associate), William Thompson, Yuan Shen (from Graduate).

Companions

Patricia Fraser Johnson, Windsor David Lewis, Helen Polanyi.

Associates

Stanley John Balsom, Joseph Stephen Patrick Barrett, Everett Large Baudoux, Ganesh Balkrishna Bhide, Charles Barton Bovill, Alexander Bowie, David Allen Brice, Herbert Buckley, William Arthur Henry Bellingham Burnside, Walter Bernard Butler, Alistair Peter Wishart Cane, George Thomas Chawner, Stanley Cooper, Ernest Charles Covell, Robert Nixon Dalkin, Leo Stanley Davies, Alfred Leslie Eggleton, Edwin Frederick Faggetter, Thomas Harry Farnsworth, Peter William Feesey (from Student), William Robert Frost, William Stanley Gibson, Austin Griffiths, Herbert Edward Hall, Cecil Albert Harwood (from Graduate), Edward Carlisle Hodgson, John Bateson Hodgson, Maurice Theobald Holdham, Robert Victor Keeling, William George Kenyon King, Lionel John Levine, Maurice Trounce Lugg, Philip de Lacey Markham (from Student), John McIntosh, John Lewis Mitchell (from Student), Frederick Charles Morton, Thomas Herbert Nettleton, Arthur Herbert Perry, Charles Archibold Phillips, William Pownall, Stanislaw Edmund Pozowski, Edwin Stanley Pryor, John Donovan Robins, George Rooney, Norman Clifford Savage, Hermann Schoenen, Albert Henry Smith, Albert William Edward Stanley, Alfred Victor Tarlton, Stanley Cecil Thorp, Gordon William Tucker, John William Jameson Truran, Leslie Donald Tyrell, Clifford Merrick Walker, Philip John Westcott.

Graduates

John Leighton Benton, Geoffrey Frank Briginshaw (from Student), Nevil John Eugene Chaplin (from Student), Lorne Campbell Dunsworth, Brian Edwards (from Student), Amin Abd-el-Messih Fahmy, Robert Jamieson, Thomas Stuart Parramore (from Student), Sidney John Smith (from

Student), Arthur Walter Turner, Hubert Beresford Walker.

Students

Kenneth Bentley, Alan Avery Blythe, Victor Edward Creighton Brooks, Richard Hill Bulloch, Robert Angus Calder, Alan John Cooper, Ernest Cummings, Laurence Bede Dawson, Frederick John Deeks, Michael Noel Dudley, Stanley Peter John Ellis, Frederick Edwin Green, Geoffrey Bertram Gurr, Gerald John Harris, John Beodie Bowman Johnston, John Edward Young King, Brian Iven Kingsnorth, Eric Jesse McKenna, Edward Matthews, Harry Usher Midwood, Donald Alexander Munro, Bernard Oliver Parker, Francis Theodore Constant Sanson, Denis John Shipway, Thomas Derrick Sills, Alan William Thompson, William Victor Tipping.

Additions to the Library

Pamphlets in italics with location reference following in brackets. Books marked * may not be taken out on loan.

B.a.344.—*Aeroplano da burbismo e da addenamento normale ed acrobatico "Fiat G.5."* (*Ufficio Tecnico Aviazione, Div. III.*) (Y.3.ii.F.)

B.a.345.—*L'Apparechio d'aviolinea Fiat "G18V."* (*Aeronautica d'Italia Societa anonima-Torino.*) (Y.3.ii.F.)

B.a.346.—*Riflessi costruttivi della velocita in aviazione. G. Gabrielli.* (*Industria Grafiche Italiana Stucchi.*) 1938. (Y.3.ii.G.)

B.a.347.—*Il Monoposto da combattimento Fiat "G.50."* (*Aeronautica d'Italia Societa anonima-Torino.*) (Y.3.ii.F.)

B.a.348.—*General specifications for the Vultee V-11G. Vultee Aircraft Div., Aviation Manufacturing Co.* (Y.3.ii.V.)

B.a.349.—*Technical description of the Vultee Model V-1A. Aeroplane Development Co.* (Y.3.ii.V.)

B.a.350.—*Vought Model V-143 single-seater fighter. Chance Vought Aircraft.* 1937. (Folio.)

B.e.67.—Soaring flight: the art of gliding. Terence Horsley. Eyre & Spottiswoode. 1944. 16/-.

B.e.68.—Gliding and soaring. A. Sitek and V. Blunt. Alliance Press. 1944. 6/-.

BB.b.115.—*Importanti particolari construttivi del "Fiat G.2." R. Giacomelli. Instituto Polarigrafico del Stato Libreria.* 1933. (PBB.1.a.10.)

BB.b.116.—*Problemi moderni nella construzione metallica degli aeroplani. G. Gabrielli. Instituto Poligrafico del Stato Libreria.* 1931. (PBB.1.a.10.)

BB.c.100.—*Fairey Metal Airscrews. Fairey Aviation Co.* (PBB.2/12.)

BB.c.101.—*New De Havilland controllable-pitch propellers for engines of 150 to 350 b.h.p.* (Y.7.a.20.)

D.a.A.36.—*Aluminium alloy extruded sections. Wrought Light Alloys Development Association.* 1944. (Y.13.c.A.)

*D.a.A.37.—International Civil Aviation Conference Chicago, 1944. U.S. Government Printing Office. 1945.

D.b.236.—*Impressioni sull'aviazione civile degli Stati Uniti. G. Gabrielli. Instituto Poligrafico dello Stato Libreria.* 1935. (PD.3/c.3.)

D.b.237, 238.—British Air Transport. H.M. Stationery Office. 1935. (PD.1/32, PD.1/33.)

D.b.240.—To-morrow's airliners, airways and airports. S. E. Veale. Pilot Press, Ltd. 1945. 15/-.

E.b.109.—*Sulla rigidezza di alcuni telai piani. G. Gabrielli.* (*Instituto Poligrafico dello Stato Libreria.*) 1938. (Y.8.a.26.)

E.b.110.—*Sull comportanento dei tubi sottili in dural assogettati a flessotorsione e sulle loro applicazione nella construzione degli aeromobili.* (*Instituto Poligrafico dello Stato Libreria.*) 1933. (Y.8 2 27.)

NOTICES

E.b.111.—*Il problema dell'a aste compresse nella construzione degli aeromobili. G. Gabrielli. Instituto Poligrafico dello Stato Libreria.* 1933. (Y.8.a.20.)

E.e.15.—*Hours of work, lost time and labour wastage. H.M. Stationery Office.* 6d. (PL.3/11.)

EE.b.83.—Aircraft Engines of the world. Paul H. Wilkinson. 1945. £2 5s.

G.a.74.—*Le materia prime nella costruzzione dei velivoli dal punto di vista autarticho. G. Gabrielli. Societa Italiana per il progresso delle scienze, Roma.* 1938. (Y.13.a.)

J.a.63.—Meteorological Observer's Handbook, 1942. Air Ministry. H.M. Stationery Office. 1944. 6/-.

J.a.64.—Meteorological Glossary, 3rd edition. Air Ministry. H.M. Stationery Office. 1944. 5/-.

L.a.52.—Aircraft Engineer's "A" Licence. G. W. Williamson. George Newnes & Co., 1945.

L.b.44.—Aviation. H. E. Wimperis. Oxford University Press. 1945. 3/6.

*L.k.48.—A Bibliography of visual literature. J. F. Fulton and others. Office of Scientific Research and Development, Washington. 1945.

S.e.93.—The Battle of Britain. H.M. Stationery Office. 1941. 3d.

S.e.94.—Target: Germany. H.M. Stationery Office. 1944.

S.e.95.—Combined Operations, 1940-1942. Ministry of Information. H.M. Stationery Office. 1942.

S.e.96.—Front Line 1940-1941. Ministry of Information. H.M. Stationery Office. 1942.

S.e.97.—The Battle of Britain. (Illustrated edition.) Ministry of Information. H.M. Stationery Office. 1941.

S.e.98.—Roof over Britain. Ministry of Information. H.M. Stationery Office. 1943.

S.e.99.—The Eighth Army. Ministry of Information. H.M. Stationery Office. 1944.

S.e.100.—The Battle of Egypt. Ministry of Information. H.M. Stationery Office. 1943.

S.e.101.—Man Power. Ministry of Information. H.M. Stationery Office. 1944.

S.e.102.—By Air to Battle. Ministry of Information. H.M. Stationery Office. 1945.

J. LAURENCE PRITCHARD,
Secretary

ESTIMATION OF STATIC LONGITUDINAL STABILITY

by

E. J. N. Archbold, B.Sc.(Eng.), Grad.R.Ae.S., Tech.M.I.Ae.S.

Mr. Archbold joined Handley-Page in 1938 as technical apprentice. He obtained his degree in 1942 at the Northampton Polytechnic. Since 1942 technical assistant in the Technical office at Handley-Page Ltd. He is secretary of the Graduate and Students' Section.

Summary

THIS paper discusses the static longitudinal stability of an aircraft in the simple case when the aerodynamic derivatives are independent of speed. An outline of the basic theory of static stability is given, accompanied by a working document, giving suitable forms for the estimation of neutral points from wind tunnel tests. A worked example is included for a typical case. No attempt is made to interpret the results, but the conclusions include a note on the C.G. margin. Loss of stability stick free, and scale effect are commented on briefly in the appendices.

1.0. *Introduction*

The estimation of the stability of an aircraft is to-day an important phase of the initial aerodynamic design. The time when it was sufficient to apply empirical formulae for the proportions of an aircraft to give stability is long past, and a serious error in initial design cannot now be corrected after flight tests without considerable complication, expense, and delay.

Paper received March 29th, 1945.

Quite accurate estimates of both longitudinal and lateral stability can now be made from little more data than a good three view general arrangement drawing. In this paper it is assumed that some such estimate has already been made, and that the design is sufficiently stabilised for wind tunnel tests to be available.

This paper, then, is in the form of a working document for the calculations needed to make a simple analysis of the static longitudinal stability, based on the minimum of wind tunnel test results. Sufficient fundamental theory is outlined to make the method comprehensible. The literature of the subject is now so wide that there seems little left to be said, but the writer feels that yet another recapitulation in simple terms will not come amiss. Further, he believes that there is a need for more working documents of the type he has attempted to produce here.

2.0. *General Discussion*

The problems of stability and control are closely connected in flight, and cannot be separated for the purposes of calculation except by means of certain assumptions

as to the type of motion considered. It is necessary first of all to differentiate between static and dynamic stability. The former is concerned only with the moments that develop on an aircraft in straight flight when it undergoes a small disturbance, the static forces on the aircraft remaining in equilibrium. Positive static stability then obtains if these moments tend to restore the aircraft to the trimmed state. In the motion that follows such a disturbance dynamic and inertia forces and moments play a part, and they must be taken into account when the dynamic stability is considered.

In the simple case we shall consider here, the aerodynamic characteristics of the aircraft are assumed to be independent of speed, and the aircraft itself is assumed to be rigid. Some types of modern aircraft operate under conditions of high speed and aerodynamic loading when compressibility effects and elastic distortion of the structure introduce variations in some characteristics which must be taken into account in the general case.

Two distinct conditions of static stability are recognised, and upon these conditions is based the whole fabric of relations between what happens to the aircraft, and what the pilot feels. These two conditions are known as " stick fixed " and " stick free " and can be described conveniently as follows :—

(*a*) With the stick (or elevators) set to give zero stick force in steady flight the aircraft is assumed disturbed and the stick held fixed throughout the subsequent motion—this is " stick fixed."

(*b*) With the elevator trim tab set to give zero stick force in steady flight the aircraft is assumed disturbed and the stick left free throughout the subsequent motion—this is " stick free."

At this stage it is convenient to define what we mean by stability as applied to an aircraft in flight. In the simplest case we can say that when an aircraft is flying in a straight steady glide and experiences a small disturbance in pitch, it is positively stable if the static moments on the aircraft tend to restore it to the initial condition. The resultant motion will be a convergence, with the mechanics of which we are not concerned when considering static stability. If the stability is negative the convergence is replaced by a divergence.

A more precise definition, which is necessary in order to maintain the relationship between the sign of the static stability and the type of motion that succeeds a disturbance is obtained by including a change of speed in the definition of static stability. The following passage, then, can be taken as a complete definition of static stability.

Suppose an aircraft is trimmed for straight flight at a given speed, incidence and engine condition, and is then flown at a slightly higher speed and at the incidence appropriate to straight flight at the higher speed. The aircraft is then statically stable stick fixed if the pitching moment tends to restore it to the original incidence. In flight the elevator position must be changed to maintain straight flight at the modified speed, the change being proportional to the restoring or disturbing moment at the new speed. The aircraft is therefore stable with stick fixed if the stick is moved forward (elevator down) to trim for straight flight at a slightly higher speed. Similarly, the aircraft is stable stick free if a push force or upward change in elevator tab angle is required for straight flight at a slightly higher speed.

It follows, therefore, that the stick movements the pilot has to make to control the aircraft are related to the stick fixed stability, while the stick forces he has to exert are related to the stick free stability.

3.0. *Theory*

3.1. *Assumptions*

In the theory of static stability for the

simple case, the following assumptions are made :—

(*a*) The force and moment coefficients C_L, C_D, C_m, C_H, are assumed to be independent of speed and air density, thus excluding the effects on them of slipstream, structural distortion and compressibility.

(*b*) The air density remains constant during the motion.

(*c*) The moment coefficients C_m and C_H are linear functions of incidence (lift coefficient) and control setting.

(*d*) The flight path angle is sufficiently small to assume that the lift is equal to the weight of the aircraft in steady flight.

(*e*) The tail lift can be neglected in comparison with the lift on the wing.

3.2 *Neutral Point*

The neutral point can be defined as that position of the aircraft centre of gravity (C.G.) for which the static stability is neutral. It is however much more convenient to regard it as that reference point about which the overall pitching moment coefficients on the aircraft is constant for small changes of incidence—a definition which follows exactly from that given above (2.0) for static stability.

The significance of the neutral point is important, and at this stage it is as well to see exactly what it is. For example if the aircraft C.G. coincides with the neutral point, stick fixed, the same elevator angle will trim the aircraft at all speeds. Similarly for the neutral point stick free, if the trim tab is set to give zero pilot's force at one speed, there will be no force on the stick at any other speed. Clearly, also, the pitching moment about a C.G. forward of the neutral point will be such as to resist an incidence change, and that about a C.G. aft of the neutral point such as to assist an incidence change.

So far, the neutral point has been referred to as belonging to the complete aircraft, but in practice it is convenient to build it up in stages from the several components of the aircraft, since it then becomes obvious how much each part of the aircraft is contributing to the stability, or otherwise, of the whole.

The neutral point of the wing alone is the so-called aerodynamic centre, which in general is very close to the quarter chord point. Nacelles, body and airscrews are usually destabilising, shifting the neutral point forward from the aerodynamic centre. The function of the tail is then to move the neutral point back, the ultimate position being aft of the aircraft C.G. if the aircraft is to be stable. We have thus arrived at the neutral point of the complete aircraft for gliding flight. Neglecting the thrust moment, which may be either stabilising or destabilising, the effect of slipstream can be treated in two parts ;—a downwash change which reduces the tail effectiveness and moves the neutral point forward; and a local airstream speed increase at the tail which increases the tail effectiveness and moves the neutral point aft again. The net effect is usually a forward shift of the neutral point relative to its glide position.

It is usual to relate the neutral point to the standard mean chord (S.M.C.) of the wing by defining it as being $h_n\bar{c}$ behind the leading edge of the S.M.C., stick fixed, and $h'_n\bar{c}$ stick free, where $\bar{c}$ is the length of the S.M.C.

The position of the neutral point in terms of the S.M.C. is simply determined from pitching moment curves. Suppose there is available a curve of pitching moment about a reference point P located $h_p\bar{c}$ from the leading edge of the S.M.C. On the basis of assumption (*c*) of paragraph (3.1) above the equation of this curve when plotted against lift coefficient C_L can be written :—

$$(C_m)_p = C_{mo} + mC_L \quad . \quad . \quad (1)$$

The pitching moment about P can also be written in terms of the lift coefficient by

taking moments about P, assuming that the lift and drag can be taken as acting through the neutral point, that drag moments are small compared with lift moments, and that incidence changes are small.

Pitching moment about P is

$$\tfrac{1}{2}\rho V^2 S\bar{c}\,[C_{m_0} - (h_n - h_p)\,C_L]$$

or in coefficient form :—

$$(C_m)_p = C_{m_0} - C_L \cdot (h_n - h_p) \qquad (2)$$

Comparing equations (1) and (2) we see directly that the slope m of the pitching moment curve is given by :—

$$m = -(h_n - h_p). \qquad (3)$$

Thus the location of the neutral point h_{s_c} is given simply by :—

$$h_n = h_p - m \quad . \qquad (4)$$

From these results three conclusions can be drawn, if P is taken to be the aircraft C.G.

(*a*) If m is positive—the neutral point lies forward of the aircraft C.G. A positive increase in incidence will then increase the overall pitching moment in the positive sense, that is tending to increase the incidence, i.e. unstable.

(*b*) If m is zero—the neutral point and the aircraft C.G. coincide. Changes of incidence do not alter the overall pitching moment and the condition is one of neutral stability.

(*c*) If m is negative—the neutral point lies aft of the aircraft C.G. A positive increase in incidence will then increase the overall pitching moment in the negative sense, that is tending to reduce the incidence, i.e. stable.

3.3. *Neutral Point Contributions*

3.3.1. *Tail.*

The neutral point contribution of the tail has been shown above to be a rearward shift equal to the change of slope of the pitching moment curve from the tail-off to the tail-on condition.

The lift coefficient of a symmetrical tailplane can be written :—

$$C_{L_T} = a_1 \alpha_T + a_2 \eta \qquad (5)$$

In the stick fixed condition η is a constant, but for stick free conditions the elevator will float so that its hinge moment is zero. Thus stick free, the elevator hinge moment :—

$$C_H = b_1 \alpha_T + b_2 \eta = 0 \qquad (6)$$

i.e.

$$\eta = -b_1/b_2 \alpha_T$$

Substituting for η in the lift coefficient equation (5) we have :—

$$C_{L_T} = a_1 \alpha_T \left(1 - \frac{a_2 b_1}{a_1 b_2}\right)$$

(Stick Free). (7)

Now the pitching moment coefficient due to tail.

$$C_{m_T} = -FVC_{L_T}$$

$$= -FV(a_1 \alpha_T + a_2 \eta)$$

(Stick Fixed) (8)

or $$= -FVa_1 \alpha_T (1 - a_2 b_1/a_1 b_2)$$

(Stick Free) (9)

Differentiating with respect to C_L

$$\frac{dC_{m_T}}{dC_L} = -FVa_1 \frac{d\alpha_T}{dC_L}$$

(Stick Fixed) (10)

or $$= -FVa_1 \left(1 - \frac{a_2 b_1}{a_1 b_2}\right) \frac{d\alpha_T}{dC_L}$$

(Stick Free) (11)

Now the tailplane incidence,

$$\alpha_T = \alpha + \eta_T - \epsilon_T. \qquad (12)$$

Thus

$$\frac{d\alpha_T}{dC_L} = \frac{d\alpha}{dC_L} - \frac{d\epsilon_T}{dC_L} = \frac{1}{a} - \frac{d\epsilon_T}{d\alpha} \cdot \frac{d\alpha}{dC_L}$$

$$= \frac{1}{a}\left(1 - \frac{d\epsilon_T}{d\alpha}\right) . \qquad (13)$$

Hence we have the neutral point shifts Δh_n and $\Delta h'_n$ due to tail in the stick fixed and free conditions, equal to the changes of pitching moment curve slope due to tail, given by

$$\Delta h_n = -\left(\frac{dC_{m_T}}{dC_L}\right) = FV \frac{a_1}{a}\left(1 - \frac{d\epsilon_T}{d\alpha}\right)$$

(Stick Fixed) (14)

simple case, the following assumptions are made :—

(*a*) The force and moment coefficients C_L, C_D, C_m, C_H, are assumed to be independent of speed and air density, thus excluding the effects on them of slipstream, structural distortion and compressibility.

(*b*) The air density remains constant during the motion.

(*c*) The moment coefficients C_m and C_H are linear functions of incidence (lift coefficient) and control setting.

(*d*) The flight path angle is sufficiently small to assume that the lift is equal to the weight of the aircraft in steady flight.

(*e*) The tail lift can be neglected in comparison with the lift on the wing.

3.2 *Neutral Point*

The neutral point can be defined as that position of the aircraft centre of gravity (C.G.) for which the static stability is neutral. It is however much more convenient to regard it as that reference point about which the overall pitching moment coefficients on the aircraft is constant for small changes of incidence—a definition which follows exactly from that given above (2.0) for static stability.

The significance of the neutral point is important, and at this stage it is as well to see exactly what it is. For example if the aircraft C.G. coincides with the neutral point, stick fixed, the same elevator angle will trim the aircraft at all speeds. Similarly for the neutral point stick free, if the trim tab is set to give zero pilot's force at one speed, there will be no force on the stick at any other speed. Clearly, also, the pitching moment about a C.G. forward of the neutral point will be such as to resist an incidence change, and that about a C.G. aft of the neutral point such as to assist an incidence change.

So far, the neutral point has been referred to as belonging to the complete aircraft, but in practice it is convenient to build it up in stages from the several components of the aircraft, since it then becomes obvious how much each part of the aircraft is contributing to the stability, or otherwise, of the whole.

The neutral point of the wing alone is the so-called aerodynamic centre, which in general is very close to the quarter chord point. Nacelles, body and airscrews are usually destabilising, shifting the neutral point forward from the aerodynamic centre. The function of the tail is then to move the neutral point back, the ultimate position being aft of the aircraft C.G. if the aircraft is to be stable. We have thus arrived at the neutral point of the complete aircraft for gliding flight. Neglecting the thrust moment, which may be either stabilising or destabilising, the effect of slipstream can be treated in two parts ;—a downwash change which reduces the tail effectiveness and moves the neutral point forward ; and a local airstream speed increase at the tail which increases the tail effectiveness and moves the neutral point aft again. The net effect is usually a forward shift of the neutral point relative to its glide position.

It is usual to relate the neutral point to the standard mean chord (S.M.C.) of the wing by defining it as being $h_n\bar{c}$ behind the leading edge of the S.M.C., stick fixed, and $h'_n\bar{c}$ stick free, where $\bar{c}$ is the length of the S.M.C.

The position of the neutral point in terms of the S.M.C. is simply determined from pitching moment curves. Suppose there is available a curve of pitching moment about a reference point P located $h_p\bar{c}$ from the leading edge of the S.M.C. On the basis of assumption (*c*) of paragraph (3.1) above the equation of this curve when plotted against lift coefficient C_L can be written :—

$$(C_m)_p = C_{mo} + mC_L \quad . \quad . \quad (1)$$

The pitching moment about P can also be written in terms of the lift coefficient by

taking moments about P, assuming that the lift and drag can be taken as acting through the neutral point, that drag moments are small compared with lift moments, and that incidence changes are small.

Pitching moment about P is

$$\tfrac{1}{2}\rho V^2 S\bar{c}\,[C_{m_0} - (h_n - h_p)\,C_L]$$

or in coefficient form :—

$$(C_m)_p = C_{m_0} - C_L\,.\,(h_n - h_p) \qquad (2)$$

Comparing equations (1) and (2) we see directly that the slope m of the pitching moment curve is given by :—

$$m = -(h_n - h_p). \qquad (3)$$

Thus the location of the neutral point h_{s_c} is given simply by :—

$$h_n = h_p - m \quad . \qquad (4)$$

From these results three conclusions can be drawn, if P is taken to be the aircraft C.G.

(*a*) If m is positive—the neutral point lies forward of the aircraft C.G. A positive increase in incidence will then increase the overall pitching moment in the positive sense, that is tending to increase the incidence, i.e. unstable.

(*b*) If m is zero—the neutral point and the aircraft C.G. coincide. Changes of incidence do not alter the overall pitching moment and the condition is one of neutral stability.

(*c*) If m is negative—the neutral point lies aft of the aircraft C.G. A positive increase in incidence will then increase the overall pitching moment in the negative sense, that is tending to reduce the incidence, i.e. stable.

3.3. *Neutral Point Contributions*

3.3.1. *Tail.*

The neutral point contribution of the tail has been shown above to be a rearward shift equal to the change of slope of the pitching moment curve from the tail-off to the tail-on condition.

The lift coefficient of a symmetrical tailplane can be written :—

$$C_{L_T} = a_1 \alpha_T + a_2 \eta \qquad (5)$$

In the stick fixed condition η is a constant, but for stick free conditions the elevator will float so that its hinge moment is zero. Thus stick free, the elevator hinge moment :—

$$C_H = b_1 \alpha_T + b_2 \eta = 0 \qquad (6)$$

i.e.

$$\eta = -b_1/b_2 \alpha_T$$

Substituting for η in the lift coefficient equation (5) we have :—

$$C_{L_T} = a_1 \alpha_T \left(1 - \frac{a_2 b_1}{a_1 b_2}\right)$$

(Stick Free). $\qquad (7)$

Now the pitching moment coefficient due to tail.

$$C_{m_T} = -FVC_{L_T}$$

$$= -FV\,(a_1 \alpha_T + a_2 \eta)$$

(Stick Fixed) $\qquad (8)$

or $\qquad = -FVa_1 \alpha_T\,(1 - a_2 b_1/a_1 b_2)$

(Stick Free) $\qquad (9)$

Differentiating with respect to C_L

$$\frac{dC_{m_T}}{dC_L} = -FVa_1 \frac{d\alpha_T}{dC_L}$$

(Stick Fixed) $\qquad (10)$

or $\qquad = -FVa_1 \left(1 - \frac{a_2 b_1}{a_1 b_2}\right) \frac{d\alpha_T}{dC_L}$

(Stick Free) $\qquad (11)$

Now the tailplane incidence,

$$\alpha_T = \alpha + \eta_T - \epsilon_T. \qquad (12)$$

Thus

$$\frac{d\alpha_T}{dC_L} = \frac{d\alpha}{dC_L} - \frac{d\epsilon_T}{dC_L} = \frac{1}{a} - \frac{d\epsilon_T}{d\alpha} \cdot \frac{d\alpha}{dC_L}$$

$$= \frac{1}{a}\left(1 - \frac{d\epsilon_T}{d\alpha}\right) . \qquad (13)$$

Hence we have the neutral point shifts Δh_n and $\Delta h'_n$ due to tail in the stick fixed and free conditions, equal to the changes of pitching moment curve slope due to tail, given by

$$\Delta h_n = -\left(\frac{dC_{m.T}}{dC_L}\right) = FV \frac{a_1}{a}\left(1 - \frac{d\epsilon_T}{d\alpha}\right)$$

(Stick Fixed) $\qquad (14)$

and $$\Delta h'_n = -\left(\frac{dC_{mT}}{dC_L}\right)$$

$$= FV\,\frac{a_1}{a}\left(1-\frac{a_2 b_1}{a_1 b_2}\right)\left(1-\frac{d\epsilon_T}{d\alpha}\right)$$

(Stick Free) (15)

3.3.2. *Airscrews*

The presence of airscrews affects the stability in as much as an airscrew rotating with its axis inclined to the local flow experiences a force normal to its axis, which causes an additional pitching moment variable with incidence. The calculation of such forces is complicated and it is sufficient for the present purpose to record the results in a simple form. The effect has been known for some time, the original work on the subject having been carried out in 1919 by Harris (R. & M. 427) and Glauert (R. & M. 642). In those days the effects of airscrew lift forces were negligible in practice, but modern high solidity airscrews have brought the effects to a stage where they are appreciable, particularly on single seat fighters and tailless aircraft. It has been found that the methods of Harris and Glauert underestimate the effect, and a more accurate theory has recently been put forward (Ref. 1).

The vertical force coefficient C_{NA} on a righthanded constant speed airscrew operated at an axial incidence ψ can be expressed as

$$C_{NA} = R\left(\frac{D^2}{S}\right)\psi$$

or

$$\frac{dC_{NA}}{d\psi} = R\left(\frac{D^2}{S}\right) \quad . \quad . \quad (16)$$

Ref. 1. gives the value of R as

$$R = M_1(J)\,C_T + M_2(J)\,B. \quad (17)$$

where $M_1(J)$ is a function of J and thrust distribution and $M_2(J)$ a function of J and the blade plan form.

It has been found that in general $M_1(J)\,C_T$ forms a small part of R compared with $M_2(J)\,B$. It is thus sufficiently accurate to use a calculation of $M_1(J)$ for a typical thrust distribution instead of calculating it for the particular thrust distribution of the airscrew used. Ref. 1. considered three widely differing plan forms, and three different thrust distributions. Comparison of the actual plan form and thrust distribution with these usually gives a fairly good fit with one of them, and values of $M_1(J)$ and $M_2(J)$ can be read from corresponding curves.

The pitching moment due to each airscrew is then

$$C_m = C_{NA}\,j/\bar{c} \quad . \quad . \quad (18)$$

Differentiating with respect to C_L

$$\frac{dC_m}{dC_L} = \frac{j}{\bar{c}}\cdot\frac{dC_{NA}}{dC_L}$$

$$\frac{dC_m}{dC_L} = \frac{j}{\bar{c}}\cdot\frac{dC_{NA}}{d\psi}\cdot\frac{d\psi}{dC_L} \quad . \quad (19)$$

Now

$$\psi = \alpha + \gamma - \epsilon_A$$

$$\frac{d\psi}{dC_L} = \frac{d\alpha}{dC_L} - \frac{d\epsilon_A}{dC_L}$$

$$\frac{d\psi}{dC_L} = \frac{d\alpha}{dC_L} - \frac{d\epsilon_A}{d\alpha}\cdot\frac{d\alpha}{dC_L} = \frac{1}{a}\left(1-\frac{d\epsilon_A}{d\alpha}\right) \quad (20)$$

Then in equation (19) :—

$$\frac{dC_m}{dC_L} = \frac{j}{\bar{c}}\cdot\frac{dC_N}{d\psi}\cdot\frac{1}{a}\left(1-\frac{d\epsilon_A}{d\alpha}\right)$$

Substituting from equations (16) and (17) we have :—

$$\frac{dC_m}{dC_L} = \frac{j}{\bar{c}}\left[M_1(J)\,C_T + M_2(J)\,B\right]\frac{D^2}{S}\cdot\frac{1}{a}\left(1-\frac{d\epsilon_A}{d\alpha}\right). \quad (21)$$

and neutral point shift due to each airscrew is :—

$$\Delta h_n = -\left(\frac{dC_m}{dC_L}\right)$$

$$= -\frac{j}{\bar{c}}\cdot\frac{D^2}{S}\cdot\left[\frac{M_1(J)C_T + M_2(J)B}{a}\right]\left(1-\frac{d\epsilon_A}{d\alpha}\right) \quad (22)$$

3.3.3. *Thrust*

The contribution of thrust to the neutral point is equal to the slope of the pitching moment curve due to thrust plotted against C_L. The condition to be fulfilled is that

of constant power as laid down in (2.0) so that assuming constant airscrew efficiency, for small changes in speed we can write :—

Thrust horsepower, per engine,

$$P = C_T \cdot \tfrac{1}{2}\rho V^2 S \cdot \left(\frac{V}{550}\right) \quad . \quad (23)$$

If k is the moment arm of the thrust line about the aircraft C.G. then the moment coefficient due to thrust can be written :—

$$C_m = \frac{NC_T k}{\bar{c}} \quad (24)$$

Differentiating with respect to C_L we have :—

$$\frac{dC_m}{dC_L} = \frac{Nk}{\bar{c}} \cdot \frac{dC_T}{dC_L} \quad . \quad (25)$$

and from equation (23) above :—

$$C_T = 550\ P/\tfrac{1}{2}\rho\ V^3 S$$

which on substituting for V in terms of W and C_L becomes

$$C_T = 550\ P\ (\tfrac{1}{2}\rho S)^{\frac{1}{2}}\ (C_L/W)^{\frac{1}{2}} \quad . \quad (26)$$

Differentiating with respect to C_L and substituting in equation (25),

$$\frac{dC_m}{dC_L} = \frac{3N}{2}\frac{k}{\bar{c}} \cdot 550P\ (\tfrac{1}{2}\rho S C_L)^{\frac{1}{2}} W^{-\frac{3}{2}} \quad (27)$$

The neutral point shift due to thrust is then

$$\Delta h_n = -\left(\frac{dC_m}{dC_L}\right)$$

$$= -\frac{3N}{2}\frac{k}{\bar{c}} \cdot 550P\ (\tfrac{1}{2}\rho S C_L)^{\frac{1}{2}} W^{-\frac{3}{2}} \quad (28)$$

3.3.4. *Slipstream*

As has been stated the neutral point contribution of slipstream is in two parts. The first is the effect that slipstream has on the downwash angle at the tail and the second the increase of local airflow speed at the tail. The combined effect can be determined from wind tunnel tests on a powered model, but an approximate method of estimating the two effects separately is given below. The degree of accuracy is higher for the downwash effect and has been checked with both tunnel and flight tests. The accuracy of the speed increase effect is not so high, but since the tunnel tests required to estimate this effect involve extensive flow exploration it is considered that the method is of some use as a first approximation.

3.3.4.1. *Slipstream effect on downwash*

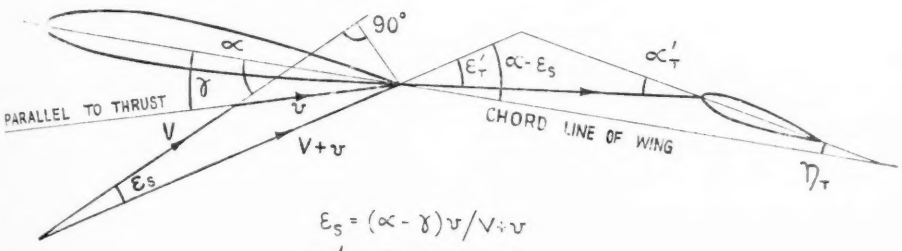
The effect of added slipstream velocity v at the wing is shown diagrammatically in Figure 1. The effect is again twofold. The effect of the added speed is a deflection of downwash and an equal reduction in local wing incidence ϵ_s given by :—

$$\epsilon_s = (\alpha - \gamma)\ v/V + v \quad . \quad (29$$

The total downwash at the tail consists of two components, the downwash due to slipstream ϵ_s and the downwash due to the wing ϵ'_T at an effective incidence of $\alpha - \epsilon_s$

Now the slip factor s is defined as :—

$$s = [(V+v)/V]^2 \quad . \quad (30)$$



$$\varepsilon_S = (\alpha - \gamma)v/V+v$$

$$\alpha'_T = \alpha + \eta_T - \varepsilon_S - \varepsilon_T$$

Fig. 1

Slipstream Effect on Downwash.

and from simple momentum theory it can be shown that :—

$$\sqrt{s} = \tfrac{1}{2}\left(1 + \sqrt{1 + \frac{8}{\pi}\cdot\frac{K_T}{J^2}}\right) \qquad (31)$$

or, assuming a slipstream area of 0.6 that of the airscrew disk,

$$\sqrt{s} = \tfrac{1}{2}\left(1 + \sqrt{1 + 8.48\frac{K_T}{J^2}}\right) \qquad (32)$$

(Ref. 2)

so that the increase of downwash at the tail can be simply calculated. The slope of total downwash at the tail with respect to incidence for constant power condition is required in order to calculate the tail contribution. As will be shown in paragraph 4.2.3 below it is convenient to calculate the actual total downwash for a number of incidences near that for which the answer is required and determine the slope of the curve of downwash against incidence graphically.

3.3.4.2. *Slipstream Effect on Local Speed at Tail*

An approximation to the slipstream speed effect on Δh_n due to the tail can be made if it can be assumed that slipstream speed and diameter remain constant from the airscrew to the tail. It should be noted that the slipstream from a tractor airscrew is broken up by the wing and this assumption is only justifiable if the reduction in slipstream speed due to the wing cancels out the final velocity increase in a free slipstream. The assumption of constant diameter would only be partially justifiable for a pusher airscrew, but for a tractor cannot be anything better than a very rough first approximation.

From Figure 1 it will be seen that the resultant slipstream makes an angle $\alpha - (\epsilon_T' + \epsilon_S + \gamma)$ with the thrust line. From the geometry of the aircraft it will then be possible to determine what fraction a_T of the tailplane area lies within a circular slipstream of diameter, say, 0.8 D at the tail. Now this fraction will be operating in a stream of speed $V\sqrt{s}$ and the remainder at speed V. Thus the total lift on the tailplane at a lift coefficient C_{LT} will be :—

$$L_T = \tfrac{1}{2}\rho V^2 S_T C_{LT}[(1 - a_T) + a_T s]$$
$$L_T = \tfrac{1}{2}\rho V^2 S_T C_{LT}[1 + a_T(s - 1)] \qquad (33)$$

The effect of slipstream speed at the tail is thus to increase the glide value of tail lift in the ratio $[1 a_T (s - 1)]/1$, a factor which can be applied as an additional tail efficiency correction.

4.0. *Method*

4.1. *Data required*

4.1.1. *Wind Tunnel Data*

Table 1 gives a list of the tunnel tests required, together with the data to be derived from them. In some cases, although lift, drag, and pitching moment measurements are specified, not all these three measurements are required, but since it is usual to measure all three together, they have been put in for the sake of completeness.

It is not proposed to go in detail into the tunnel technique used, nor into the derivation of the basic data from the tunnel tests. More elaborate tests than those detailed will give correspondingly more elaborate data, such as pitching moment due to airscrews at various thrust coefficients, and changes in pitching moment due to slipstream. Only these tests required for the method described here are given. The following data are to be derived :—

(*a*) Curve of C_L against α, C_D and C_m against C_L for the complete aircraft less tail, flaps up and down.

(*b*) Curves of C_m due to wing, body and nacelles separately, against C_L with interference effects included.

(*c*) Curves of ϵ_T against α, flaps up and down.

(*d*) Curves of F against C_L flaps up and down.

(*e*) Curves of C_{LT} and C_H against a_T and η with η and a_T as parameters.

The data included in (*a*), (*b*), and (*e*) can easily be derived from tests A1 to A5 and B3 of table 1 and nothing need be said

TABLE 1

TABLE I

WIND TUNNEL TESTS

TEST	MODEL	CONDITIONS	MEASUREMENTS	DERIVED DATA
A.1	Wing alone	Flaps up and down. Full α range	Lift, drag, and pitching moment.	Lift curve and drag polar for complete aircraft less tail.
A.2	Wing + body			Separate pitching moment curves for wing, body and nacelles.
A.3	Wing + nacelles			
A 4	Wing + body + nacelles			
A.5	Body alone	Ful. α range	Lift, drag, and pitching moment.	Overall pitching moment complete aircraft less tail.
B.1	Complete aircraft	Flaps up & down, full α range (*a*) η_T varied, η fixed. *b*) η varied, η_T fixed.	Pitching moment	Pitching moments with tail on for downwash and tail efficiences.
B.2	Body + tail (same as complete scale model)	η_T fixed at design value. α_T and η varied.	Pitching moment	Pitching moment due to tail for tail efficiencies.
B.3	Body + tail (large scale)	η_T fixed at design value α_T and η varied.	Lift and elevator hinge moment.	Tail characteristics. a_1, a_2, b_1, b_2.

NOTE :—All pitching moment measurements taken about the same pitch point.
Tests A1 to A5, B1 and B2 at same speed.
Test B3 may be at a different speed if necessary, the object of the larger scale being a higher Reynolds number to improve the accuracy of the results.

about the method of derivation. Typical curves showing the general form of (*a*) and (*b*) are given in Figures 2 to 4 and 9. That included in (*c*) and (*d*) is not so obvious and a little explanation is necessary.

pitching moment curves for a range of values of tail setting to the zero lift line of the wing, as has been done in Figure 5, the intersection points wil give simultaneous values of α and η_T at which the pitching moments

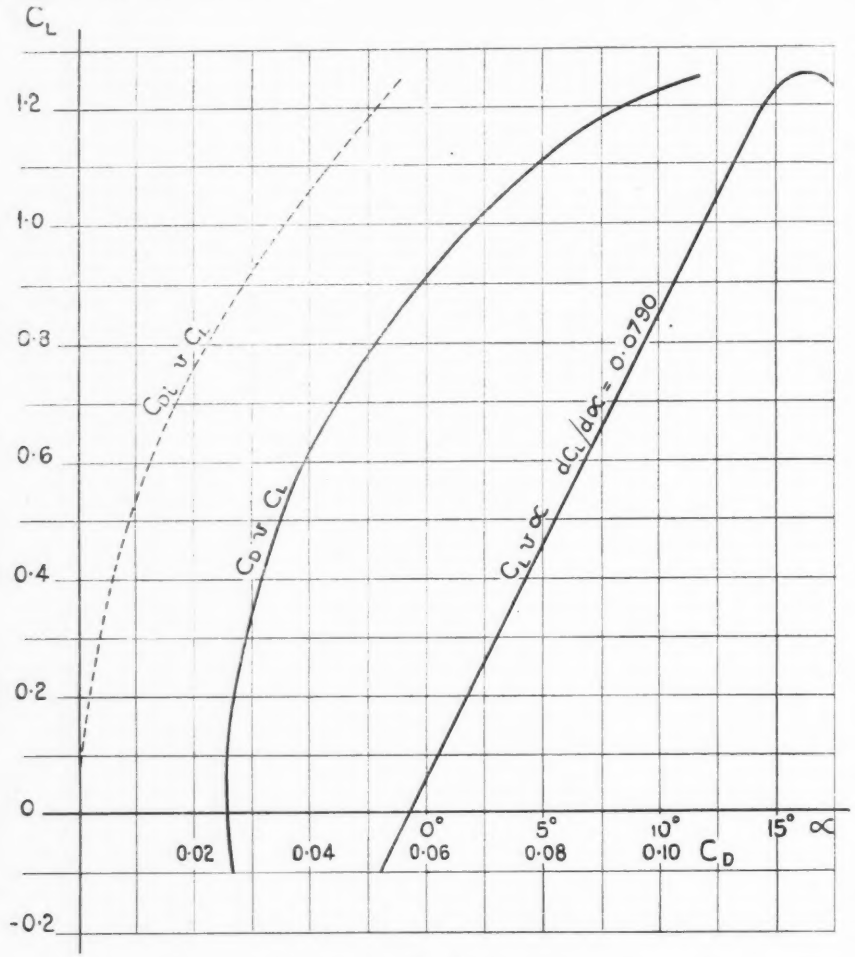


Fig. 2
Lift Curve and Drag Polar. Flaps Up.

First comes the derivation of downwash. Clearly, when the effective tail incidence is zero, the pitching moment due to tail is also zero if the tail is of symmetrical section. If a curve of pitching moment for complete aircraft less tail is plotted over a set of tail off and on are equal. Clearly at these points, the tail incidence α_T is zero. Then from equation 12

$$\alpha_T = \alpha + \eta_T - \epsilon_T$$

which can now be equated to zero at each

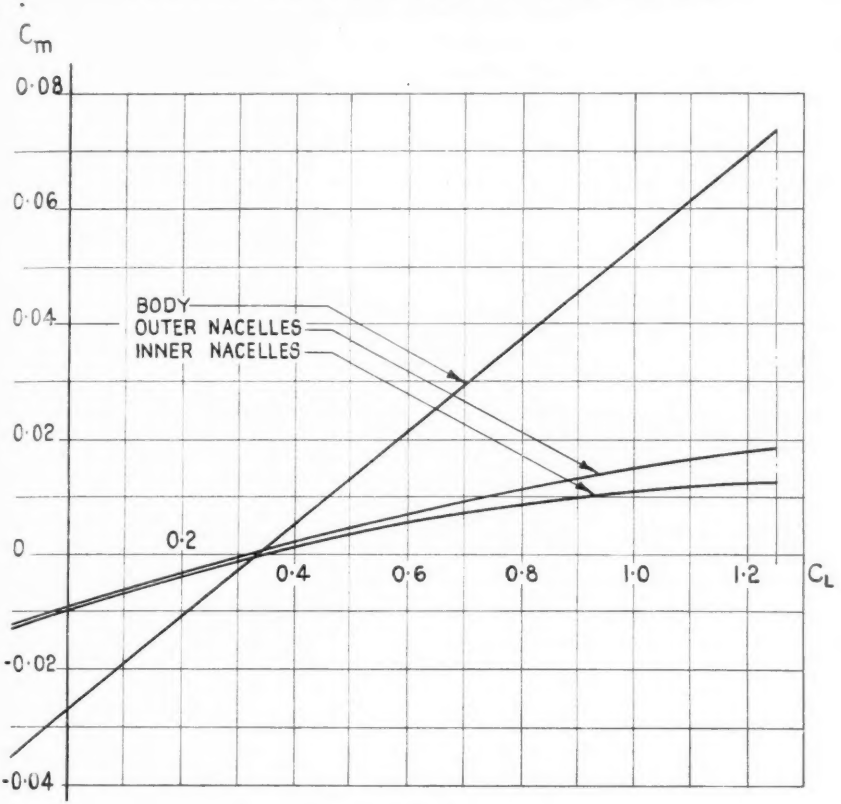


Fig. 3
Body and Nacelle Pitching Moments.

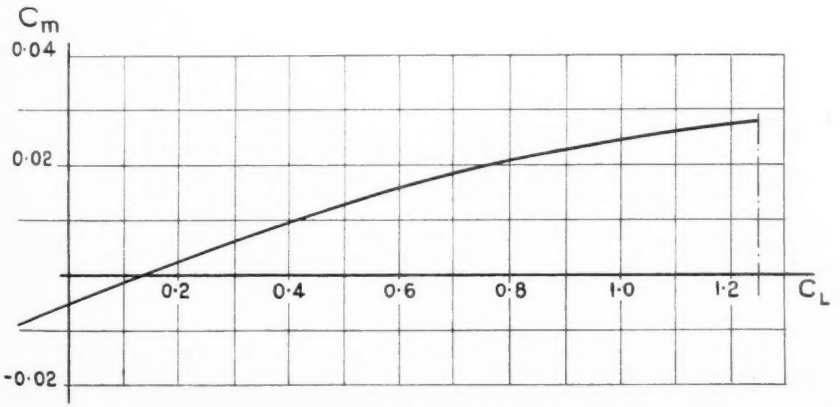


Fig. 4
Overall Wing Pitching Moment. Flaps Up.

TABLE II

DATA OTHER THAN WIND TUNNEL DERIVATIONS

A. Data common to all cases.			
1. Aircraft geometry.			
Span	b	111 ft.	
Wing area, gross	S	1500 sq. ft.	
Standard mean chord	$\bar{c}$	13.5 ft.	
S.M.C. leading edge location relative to C.G. origin		gives h	
Tail arm	l	44.5 ft.	
Tail plane area, gross	S_T	330 sq. ft.	
Tail volume coefficient	V	0.726	
Thrust line inclination to wing chord line	γ	−3.0 degrees	
2. Power plant and airscrews.			
Number of engines	N	4	
Airscrew diameter	D	13.0 ft.	
Number of blades per airscrew	B	4	
Airscrew blade plan form		Type III	
Typical airscrew thrust distribution		Type C	
$d\epsilon_A/d\alpha$ at airscrews		−0.18	
B. Data specific to each case.			
1. Flight Condition.			
All up weight	W	75000 lb.	
Speed	V	230 mph. T.A.S.	
Relative air density	σ	0.533	
Lift coefficient	C_L	0.7	
Incidence of wing chord line	a	8.0 degrees	
2. Power Conditions.			
Thrust horsepower	P	700	
Engine R.P.M.		2000	
Airscrew r.p.s	n	14.8	
3. C.G. locations.			
Relative to C.G. origin	$\bar{x}$, $\bar{y}$	48.0/34.0 ins.	
Relative to S.M.C.	h	0.282	
Relative to reference point	$\Delta\bar{x}$, $\Delta\bar{y}$	2.0/10.0ins.	
4. Other geometry.			
Thrust line relative to C.G.	k	3.0 ft.	
Airscrew disk, elative to C.G.	j	12.0 ft.	

intersection point, the downwash at the tail is given by

$$\epsilon_T = \alpha + \eta_T \quad . \quad . \quad (34)$$

There are a number of similar methods of deriving tail efficiency from tunnel tests, and a representative method is as follows.

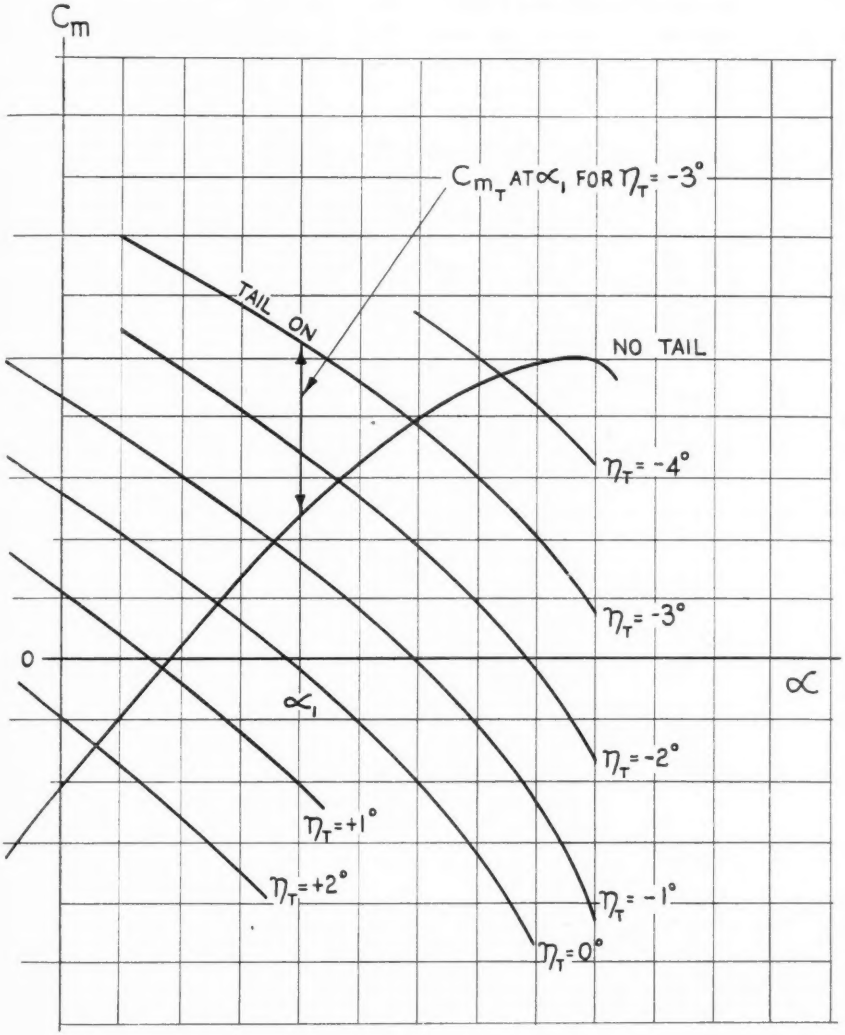


Fig. 5
Diagram showing Derivation of Downwash and Tail Efficiency.

Coming now to the derivation of tail efficiency, we can define the efficiency F as:—

$$F = \frac{dC_{mT}/d\alpha_T \text{ at a given } \alpha_T \text{ on complete model}}{dC_{mT}/d\alpha_T \text{ at same } \alpha_T \text{ without wing}} \quad (35)$$

Referring again to Figure 5 it will be seen that at any value of α, say α_1, the pitching moments due to tail at various values of η_T are given by the increments between the tail off curve and tail on curves for the appropri-

ate η_T. From these values it is possible to plot curves of C_{mT} against η_T for a range of incidences. Now from equation (12) above it is clear that $dC_{mT}/d\eta_T$ for constant α is equal to $dC_{mT}/d\alpha_T$.

From tunnel test B.2 of Table 1 curves of $dC_{mT}/d\alpha_T$ for constant values of α can be obtained. It is thus possible to calculate F for a range of values of α whence a curve of F against C_L can readily be obtained. Typical curves of ϵ_T and F are given in Figures 6 and 7.

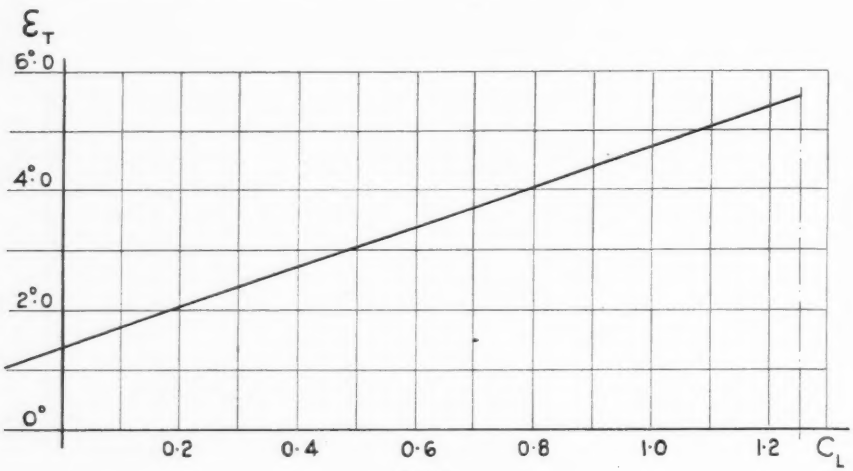


Fig. 6
Downwash at Tail. Flaps Up.

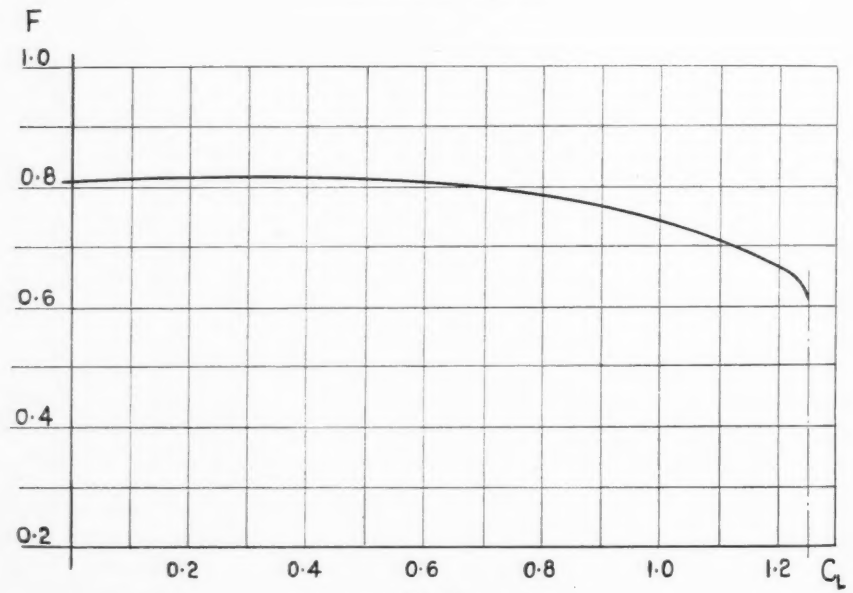


Fig. 7
Tail Efficiency. Flaps Up.

4.1.2. *Other Data*

The essential data other than that derived from wind tunnel tests, which is required for the calculation, is summarised for convenience in Table II.

4.2. *Calculations*

4.2.1. *Correction of Pitching Moments to Aircraft C.G. (Table III)*

The assumption of small drag moments made in writing equation (2) above needs some correction at this stage. It still remains true for small changes of incidence for a particular C.G. but since the aircraft C.G. may differ considerably in the vertical direction from the reference point about which moments were measured in the tunnel it is necessary to take drag moments in to account when correcting the tunnel pitching moments to the aircraft C.G.

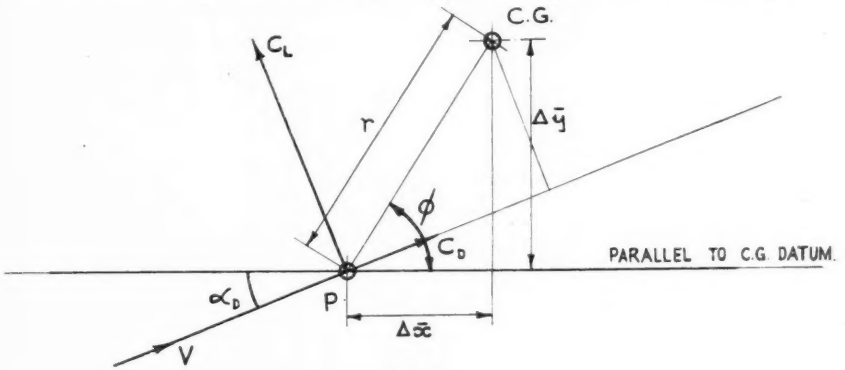


Fig. 8
Correction of Pitching Moments to Aircraft C.G.

In the general case, when the aircraft C.G. differs from the reference point P (in figure 8) by increments $\Delta\bar{x}$ and $\Delta\bar{y}$ measured parallel and normal respectively to the horizontal C.G. datum, the pitching moment about the aircraft C.G. is given by:—

$$(C_m)_{C.G.} = (C_m)_P + \Delta C_m$$

where

$$\Delta C_m = [C_L \cos(\alpha_D - \phi) + C_D \sin(\alpha_D - \phi)]r/\bar{c} \quad . \quad (36)$$

The first step in the calculations is thus to correct the pitching moments for the complete aircraft less tail to the aircraft C.G. Strictly speaking this should be done for each C.G. that is to be considered. Usually however only one or two C.G.'s near the aft limit for the aircraft are concerned, and small changes of less than an inch horizontally can be neglected.

4.2.2. *Neutral Point, without Tail and Airscrews, Glide (Table IV)*

The neutral point for the bare aircraft less tail and airscrews for the no slipstream case is now readily derived from equation (4), the slope m of the pitching moment curve being read off at the C_L appropriate to each flight case.

4.2.3. *Thrust and Slipstream Effects (Table V)*

It is convenient to calculate all of these effects at the same time. The thrust effect is given by equation (28) and the slipstream effects involve the use of equation (29) and the correction factor $[(1 + a_T)(s - 1)]$ from equation (33).

4.2.4. *Tail Contribution (Table VI)*

Equations (14) and (15) give expressions for Δh_n and $\Delta h_n'$ due to tail, stick fixed and free. Substitution of $d(\epsilon_S + \epsilon_T')/da$ for $d\epsilon_T/da$ and of $F[1 + a_T(s - 1)]$ for F

TABLE III

CORRECTION OF PITCHING MOMENTS TO AIRCRAFT C.G.

Reference point location $\bar{x} = 46.0''$ $\bar{y} = 24.0''$ $h = 0.270$
Flight C.G. location $\bar{x} = 48.0''$ $\bar{y} = 34.0''$ $h = 0.282$

CASE	$\bar{x}''$	$\bar{y}''$	$\Delta\bar{x}''$	$\Delta\bar{y}''$	$\Delta\bar{x}^2$	$\Delta\bar{y}^2$	r^2	r''	$\Delta\bar{y}/\Delta\bar{x}$	ϕ°
1	48.0	44.0	2.0	10.0	4.0	100.0	104.0	10.2	5.0	78.7
2 etc.										

CASE 1.

C_L	—0.1	0	0.2	0.4	0.6	0.8	1.0	1.2	1.25
a wing chord line	—2.05	—0.80	+1.70	4.25	6.80	9.35	11.85	14.50	16.50
a_D C.G. datum	—4.05	—2.80	—0.30	+2.25	4.80	7.35	9.85	12.50	14.50
C_D less tail and airscrews	0.0233	0.0223	0.0232	0.0278	0.0356	0.0480	0.0650	0.0872	0.1068
C_m less tail and airscrews	—0.0702	—0.0521	—0.0168	+0.0172	0.0498	0.0790	0.1048	0.1279	0.1326
$a_D - \phi$	—82.75	—81.50	—79.00	—76.45	—73.90	—71.35	—68.85	—66.20	—64.20
$\cos(a_D - \phi)$	0.1262	0.1478	0.1908	0.2353	0.2773	0.3198	0.3608	0.4051	0.4352
$\sin(a_D - \phi)$	—0.9920	—0.9890	—0.9816	—0.9722	—0.9608	—0.9475	—0.9326	—0.9150	—0.9003
$C_L \cos(a_D - \phi) = p$	—0.0126	0	0.0382	0.0941	0.1664	0.2558	0.3608	0.4861	0.5450
$C_D \sin(a_D - \phi) = q$	—0.0231	—0.0221	—0.0228	—0.0270	—0.0342	—0.0455	—0.0605	—0.0798	—0.0960
$p + q$	—0.0357	—0.0221	+0.0154	0.0671	0.1322	0.2103	0.3003	0.4063	0.4490
$\Delta C_m = (p + q)\, r/\bar{c}$	—0.0022	—0.0014	+0.0010	0.0042	0.0083	0.0133	0.0189	0.0256	0.0283
Corrected C_m	—0.0724	—0.0535	—0.0158	+0.0214	0.0581	0.0923	0.1237	0.1535	0.1609

TABLE IV

NEUTRAL POINT, LESS TAIL AND AIRSCREWS, GLIDE

CASE	1	2 etc.
C_L	0.7	
dC_m/dC_L	0.171	
C.G. h	0.282	
h_o	0.111	

TABLE V

THRUST AND SLIPSTREAM EFFECTS

CASE	1			2 etc.
C_L	0.5	0.7	0.8	
V f.p.s.	397	336	314	
Thrust horsepower P	700	700	700	
Thrust T_N net lb.	970	1145	1225	
Thrust T_G gross lb.	1020	1205	1290	
$K_T/J^2 = T_G/\rho V^2 D^2$	0.0302	0.0497	0.0610	
$(\frac{1}{2}\rho S C_L)^{\frac{1}{2}}$		0.815		
$W^{3/2}$		20.5×10^6		
$k/\bar{c}$		0.222		
Δh_n due to thrust		—0.020		
a	5.5	8.0	9.4	
$a-\gamma$	2.5	5.0	6.4	
s	1.124	1.206	1.243	
$v/V+v$	0.060	0.088	0.105	
ϵ_s	0.15	0.44	0.63	
$a-\epsilon_s$	5.35	7.56	8.77	
ϵ'_T	3.00	3.60	3.90	
$\epsilon_s+\epsilon'_T$	3.15	4.04	4.53	
$d(\epsilon_s+\epsilon_T')/da$		0.350		
$a-(\epsilon_s+\epsilon_T'+\gamma)$		0.96		
Rise of slip disk at tail ft.		0.745		
a_T		0.40		
$a_T.(s-1)$		0.08		
$1+a_T(s-1)$		1.080		

extend these equations to give Δh_n and $\Delta h_n'$ in the slipstream case.

4.2.5. *Airscrew Contribution (Table VII)*

The planform and typical thrust distribution curve of the airscrew used are compared with the curves of Ref. 1. and the types which give the best fit chosen. The remainder of the calculation is simple as shown in Table VII. It should be noted that a, the slope of the lift curve must be in terms of radians in equation (22). No method of determining $d\epsilon_A/d\alpha$ at the airscrew has been mentioned in the wind tunnel tests required, as the test would involve flow exploration. Generalised data is sufficiently accurate for the purpose.

4.2.6. *Neutral Point, Complete Machine, Glide and Power on (Table VIII)*

The various contributions to neutral point position can now be added up. The neutral point for the complete machine in the glide is given by

$$h_n \text{ (or } h_n') = h_o + N \cdot \Delta h_n \text{ (due to airscrews, zero thrust)} + \Delta h_n \text{ (or } \Delta h_n') \text{ (due to tail, stick fixed or free)} \quad (37)$$

TABLE VI

TAIL CONTRIBUTION

a_1	=	0.0675	a	=	0.0790	$a_2 b_1/a_1 b_2$	= 0.0897
a_2	=	0.0363	a_1/a	=	0.844	$1 - a_2 b_1/a_1 b_2$	= 0.9103
b_1	=	—0.0005	a_2/a_1	=	0.537		
b_2	=	—0.0030	b_1/b_2	=	0.167		

CASE	1	2 etc.
C_L	0.7	
V	0.726	
F	0.80	
$d\epsilon_T/d\alpha$ (no slipstream)	0.26	
$1 - d\epsilon_T/d\alpha$	0.74	
Δh_n Stick Fixed, Glide	0.362	
$\Delta h_n'$ Stick Free, Glide	0.330	
$d(\epsilon_S + \epsilon_T')/d\alpha$ (with slipstream)	0.350	
$1 - d(\epsilon_S + \epsilon_T')d\alpha$	0.65	
$1 + a_T(s-1)$	1.08	
$F[1 + a_T(s-1)]$	0.865	
Δh_n Stick Fixed Power On.	0.344	
$\Delta h_n'$ Stick Free, Power On.	0.314	

or

$$h_n \text{ (or } h_n') = h_o + N\Delta h_n \text{ (due to airscrews and thrust)} + \Delta h_n \text{ (or } \Delta h_n') \text{ (due to tail, stick fixed or free)} \quad . \quad . \quad . \quad (38)$$

where the appropriate power on values are used.

Table VIII summarises the results in a form which shows how the complete machine neutral point is built up. The item for C.G. displacement is included to show the effect of the C.G. being widely different from the test reference point, which will usually be located near the aerodynamic centre either of the wing alone or of the complete aircraft less tail. The items for Δh_n due to body and nacelles are simply the slopes of the individual curves of pitching moment about the test reference point and serve as a check on the value of h_o obtained from the complete machine before correction of the pitching moments to the aircraft C.G.

4.2.7. *Worked Example*

A worked example is shown in Tables III to VIII based on data given in Table II, Figures 2 to 7 and Figure 9. The aircraft considered is a large four engined monoplane flying at 75,000 lb. all up weight. Only one flight case is considered, that for continuous cruising with the C.G. at a typical full load position for a transport aircraft.

5.0. *Concluding Remarks*

Aircraft design has passed the stage at

TABLE VII

AIRSCREW CONTRIBUTION

Selected plan form type of Ref. 1. . . . . Type III
Selected thrust distribution type of Ref. 1. . . . . Type C

D	= 13.0 ft.	a	= 4.53	$d\epsilon_A/d\alpha$	(assumed)	=	—0.180
B	= 4	N	= 4		$1 - d\epsilon_A/d\alpha$	=	1.180
j	= 12.0 ft.	$j/\bar{c}$	= 0.89		D^2/S	=	0.1127

CASE		1	2 etc.
C_L		0.70	
V	f.p.s.	336	
Engine r.p.m.		2000	
Airscrew r.p.s. n		14.80	
$J = V/nD$		1.746	
$M_2\,(J)$		0.062	
$M_2\,(J).\,B$		0.248	
Δh_n (zero thrust.)		—0.026	
T_G gross thrust.	lb.	1205	
$C_T = T_G/\frac{1}{2}\rho SV^2$		0.0112	
$M_1\,(J)$		0.140	
$M_1\,(J).\,C_T$		0.00157	
$[M_1\,(J)\,C_T + M_2\,(J).\,B]$		0.250	
Δh_n (with thrust.)		—0.026	

TABLE VIII

NEUTRAL POINT, COMPLETE AIRCRAFT. GLIDE AND POWER ON

CASE		1	2
Weight	lb.	75000	
Altitude	ft.	20000	
Speed T.A.S.	m.p.h.	230	
Speed E.A.S.	m.p.h.	167	
Lift coefficient		0.7	
Engine R.P.M.		2000	
Brake horsepower/engine		850	
Thrust horsepower/engine		700	
Gross thrust per engine.	lb.	1205	
Aerodynamic centre, wing alone.		0.254	
Δh_n due to body.		—0.081	
Δh_n due to nacelles.		—0.037	
Δh_n due to C.G. displacement from reference point.		—0.025	
Neutral point, complete a/c less tail and airscrews.		0.111	
Δh_n due to airscrews, glide.		—0.026	
Neutral point, complete a/c less tail, glide		0.085	
Δh_n due to tail, stick fixed, glide.		0.362	
Δh_n ,, ,, ,, stick free, ,,		0.330	
Neutral point, stick fixed, glide.		0.447	
,, ,, stick free, ,,		0.415	
Δh_n due to thrust.		—0.020	
Δh_n due to airscrews, power on.		—0.026	
Neutral point, complete a/c less tail, power on.		0.065	
Δh_n due to tail, stick fixed, power on.		0.344	
Δh_n ,, ,, ,, stick free, ,, ,,		0.314	
Neutral point, stick fixed, power on.		0.409	
,, ,, stick free, ,, ,,		0.379	
C.G. Location.		0.282	
C.G. Margin, stick fixed, glide.		0.165	
,, ,, stick free, ,,		0.133	
,, ,, stick fixed, power on.		0.127	
,, ,, stick free, ,, ,,		0.097	

which major changes in the layout can be made after flight tests, and it is therefore necessary that an early check of the static longitudinal stability should be made.

Static stability has been defined as the tendency of the pitching moments resulting from a disturbance to restore the aircraft to its undisturbed state. It has been shown that a convenient measure of this restoring tendency is the position of the neutral point relative to the aircraft C.G.

This paper sets out the calculation of neutral point position from simple wind tunnel tests and generalised data in a form suitable for routine calculations. The stability is then measured by the margin, in terms of the S.M.C. between the neutral point and the aircraft C.G., that is the C.G. margin, or as it may be termed in the simple case, the static margin.

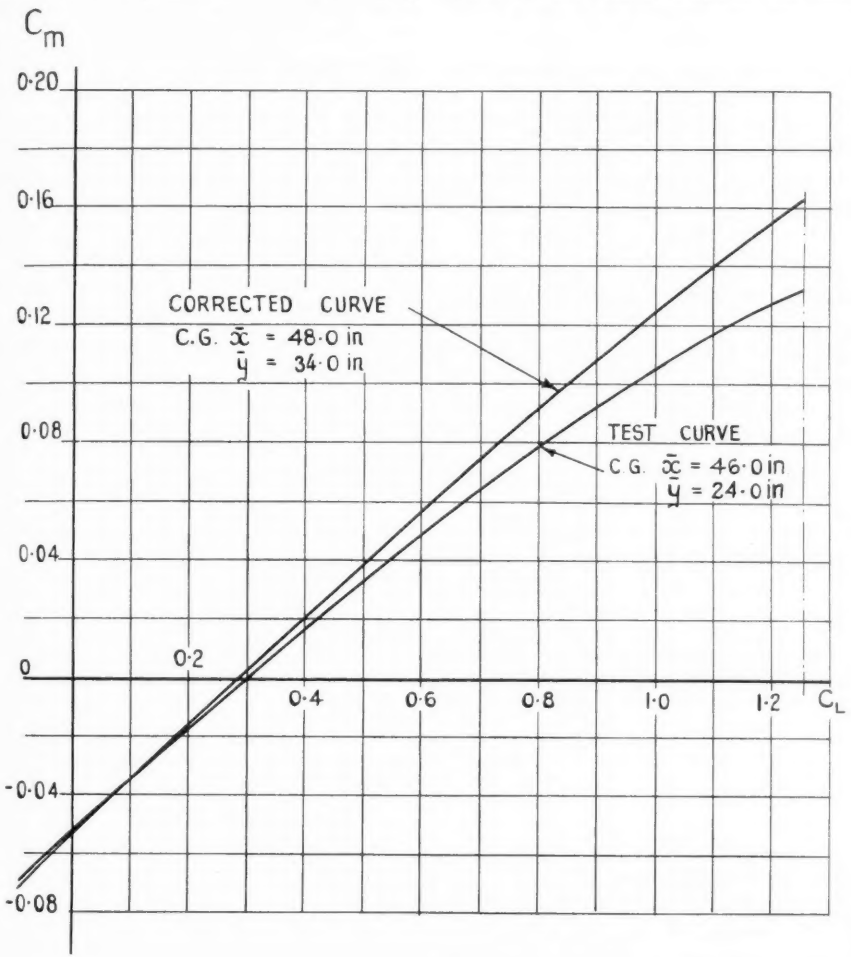


Fig. 9
Overall Pitching Moments. Flaps Up.

It is becoming usual for a new aircraft specification to include a minimum value

of the C.G. margin which the designer must obtain. The practise of specifying a C.G. margin for a particular type is however as yet, in its infancy. At present, specified values are regarded as subject to revision in the light of further flight experience. Their relation to the safety of the aircraft, the degree of manoeuvrability required of it and the comfort of the occupants, needs much further study. In particular the degree of static stability compatible with comfort in flight is of increasing importance in the design of aircraft for civil passenger operation.

ACKNOWLEDGMENTS

The author is indebted to Mr. R. S. Stafford, F.R.Ae.S., of Handley Page, Ltd., for permission to publish this paper, and to Messrs. F. Radcliffe, F.R.Ae.S., and C. O. Vernon, A.F.R.Ae.S., for their encouragement and helpful criticism.

REFERENCES

1. Rumph, L. B., White, R. J., and Grumman, H. R.
   Propeller forces due to yaw and their effect on airplane stability. J.Ae.Sc., Vol. 9, No. 12, page 465.
2. Stafford, R. S.
   The propulsive efficiency of an airscrew.
   The Aircraft Engineer, March 30th, 1933.

APPENDIX A

Loss of Stability Stick Free

A study of equations (14) and (15) shows that the change of Δh_n due to tail from the stick fixed to the stick free condition depends upon the sign and magnitude of the quantity $a_2 . b_1/a_1 . b_2$. If this quantity is positive there will be a loss of stability stick free as compared with stick fixed.

Now the components of this quantity are the characteristics of the tailplane and elevator, a_1 and a_2 being lift curve slopes and therefore always positive. The slope a_1 is primarily a function of tailplane section and aspect ratio, and a_2 a function of elevator size. Thus both a_1 and a_2 can be treated as being fixed for a given design by the Δh_n due to tail required stick fixed and the elevator size required for control at low speeds.

The hinge moment characteristics b_1 and b_2 are both functions of the elevator section and the degree of aerodynamic balance provided. It is here then that the designer has some scope for controlling the stick free loss. The slope b_2 of the curve of C_H against η is found always to be negative, its magnitude depending upon the degree of aerodynamic balance. The extent to which the elevator can be lightened however is limited by safety considerations and the pilot's idea of a sensitive control. The slope b_1 of the curve of C_H against α_T can however be varied in sign from negative to positive without b_2 becoming unreasonably small. For example, an elevator with zero aerodynamic balance might have a b_1 of about —0.0030 per degree. With 25% of set-back hinge balance this might become about —0.0015, but with 9% of horn balance it could become as much as +0.0030.

By careful design it is possible then to minimise the stick free loss and even to produce a gain in stability on freeing the stick, a condition which will occur with b_1 positive, the quantity $a_2 . b_1/a_1 . b_2$ being then negative. It is considered unwise to go very far in this direction, however.

APPENDIX B

Scale Effect on Neutral Points

When estimating C.G. margins from tunnel tests some allowance must be made for scale effect on the test results. Examination of equations (37) and (38) shows that the neutral point position can be written :

$$h_n = h_o + FV\frac{a_1}{a}\left(1 - \frac{d\epsilon_T}{d\alpha}\right) \quad . \qquad (39)$$

or Stick Fixed

$$h_n = h_o + FV\frac{a_1}{a}\left(1-\frac{a_2 b_1}{a_1 b_2}\right)\left(1-\frac{d\epsilon_T}{d\alpha}\right) \quad (40)$$

Stick Free

where h_o is the aerodynamic centre of the complete aircraft less tail, when allowances have been made for airscrew and thrust effects.

In these equations, h_o, a_1, a, and $d\epsilon_T/d\alpha$ suffer scale effects if they are derived from tunnel tests. It is not possible to calculate these effects and at best they can only be estimated from generalised data. It is not possible here to go into the matter in detail and the best that can be done is to indicate the order of the corrections to be applied to a C.G. margin based on tunnel tests.

The order of the correction will depend upon the Reynolds number at which the tests were carried out and the following notes are a rough guide to the effect to be expected.

(*a*) Tests at $R < 10^6$.

Overall effects are likely to be very large at these low speeds and the results are usually most unsatisfactory. Δh_n due to scale effect is probably at least —0.05.

(*b*) Tests at $R = 10^6$ to 6×10^6.

Scale effect on a_1,

$\Delta h_n = -0.02$ to -0.04.

Scale effect on h_o,

$\Delta h_n = 0$ to $+0.01$.

(*c*) Tests at $R > 6 \times 10^6$.

Scale effects are likely to be very small and can be neglected for a first approximation.

TABLE IX

LIST OF SYMBOLS

a	=	$dC_L/d\alpha$, no tail
a_1	=	$dC_{LT}/d\alpha_T$
a_2	=	$dC_{LT}/d\eta$
a_T	=	fraction of tailplane area in slipstream.
B	=	number of blades per airscrew.
b	=	span (ft.)
b_1	=	$dC_H/d\alpha_T$
b_2	=	$dC_H/d\eta$
C_D	=	(drag on complete to aircraft)/$\frac{1}{2}\rho V^2 S$
C_L	=	(lift on complete aircraft)/$\frac{1}{2}\rho V^2 S$
C_{LT}	=	(lift on tailplane)/$\frac{1}{2}\rho V^2 S_T$
C_m	=	(pitching moment)/$\frac{1}{2}\rho V^2 S\bar{c}$
C_{m_o}	=	value of C_m when $C_L = 0$.
C_{mT}	=	(pitching moment due to tail)/$\frac{1}{2}\rho V^2 S\bar{c}$
C_{N_A}	=	see equation (16)
C_H	=	(elevator hinge moment)/$\frac{1}{2}\rho V^2 S_\eta c_\eta$
$\bar{c}$	=	standard mean chord of wing = S/b (ft.
c_η	=	mean chord of elevator (ft.)
D	=	airscrew diameter (ft.)
F	=	tail efficiency on glide.
F'	=	tail efficiency power on = $F\,[1 + a_T(s-1)]$
$h\bar{c}$	=	distance of aircraft C.G. aft of leading edge of S.M.C. (ft.)
h_n	=	value of h when C.G. coincides with neutral point stick fixed.

h'_n = value of h when C.G. coincides with neutral point stick free.
H_n = $h_n - h$ i.e. C.G. margin stick fixed.
H'_n = $h_n' - h$ i.e. C.G. margin stick free.
h° = value of h at aerodynamic centre without tail and airscrews, glide.
J = advance ratio $= V/nD$.
j = distance of airscrew forward of aircraft C.G. (ft.)
K_T = airscrew thrust coefficient $= T_G/\rho n^2 D^4$.
k = distance of thrust line below aircraft C.G. (ft.)
l = distance of aerodynamic centre of tailplane aft of aerodynamic centre of aircraft without tail.
m = dC_m/dC_L
n = airscrew revolutions per second.
P = thrust horsepower per engine.
R = see equation (16).
r = see Fig. 8.
S = gross wing area (sq. ft.)
S_T = gross tailplane area (sq. ft.)
$S\eta$ = net elevator area (sq. ft.)
s = slipstream factor, see equation (31) & (32)
T_N = net thrust per engine $= 550\ P/V$.
T_G = gross thrust per engine = (T_N + drag increase due to slipstream).
V = speed (ft./sec.)
V = tail volume coefficient $= S_T l/S\bar{c}$
v = added speed in slipstream (ft./sec.)
W = all up weight (lb.)
$(\bar{x}, \bar{y})$ = location of aircraft C.G. relative to C.G. origin.
α = incidence of chord line of wing relative to flight path.
α_T = incidence of tailplane to local wind direction at tail.
α_D = incidence of horizontal C.G. datum relative to flight path.
γ = inclination of thrust line relative to chord line of wing.
ϵ_A = angle of downwash at airscrew.
ϵ_S = angle of downwash due to slipstream at tail.
ϵ_T = angle of downwash due to wing at tail.
ϵ_T' = angle of downwash at tail due to wing at incidence $(\alpha - \epsilon_S)$
η = elevator angle.
η_T = setting of tailplane relative to chord line of wing.
ρ = air density.
σ = relative density.
φ = see Fig. 8.
ψ = angle between airscrew axis and local wind direction at airscrew disk.

THE EULER CRITICAL LOAD FOR PINNED-PINNED 'POLYNOMIAL' TAPERED STRUTS

by

F. J. Turton, B Sc., A.R.C.S.

F. J. Turton took his B.Sc. with honours at London University in 1914, and served in the Royal Navy, 1915-1919. Following his demobilization he became a lecturer in mathematics at the City and Guilds College. He has written numerous papers on structural problems which have been published in the Philosophical Magazine and the Journal of the Society.

§1. The differential equation for the deflection of a tapered strut cannot usually be solved by formal methods; we propose to attack the problem in the reverse direction; given the deflection-curve as a polynomial, we find the shape of the longitudinal section for struts of given strength. It will appear that the shapes so found are quite different from those for struts "of uniform stress" yet it is possible to get substantial saving in weight for a given strength (for some of the examples up to 11 per cent., the theoretical maximum being 13.4 per cent.

§2. *Notation*

A solid strut of length $2l$ subject to axial thrust P at the pinned-pinned ends has similar sections symmetrical about their neutral axes and similarly situated with respect to the longitudinal axis, $y=0$; x is measured outwards from the centre along that axis and at $\pm x$ the deflection is y, a typical lateral measurement t, the least second moment of the section I, and the area A; the corresponding values at $x=0$ are indicated by attaching a suffix $_o$; and at $x/l=1$ by attaching suffix $_1$. Non-dimensional variables $X=x/l$, $T=t/t_o$ are used and $k^2=Pl^2/EI_o$. Suffix $_u$ is used when referring to a uniform strut.

Paper received September, 1945.

Then the volume of the strut

$$=2\int_0^1 A\,dx = 2lA_o\int_0^1 (A/A_o)\,dX = 2lA_o\int_0^1 T^2\,dX.$$

Also

$$P=k^2EI_o/l^2$$

and for a uniform strut of the same strength

$$P=\pi^2EI_u/4l^2$$

so that

$$I_o/I_u=\pi^2/4k^2=t_o^4/t_u^4=A_o^2/A_u^2$$

Hence the ratio of their volumes

$$=2lA_o\int_0^1 T^2dX/2lA_u=(\pi/2k)\int_0^1 T^2.dX$$

This ratio is therefore the ratio of the weight of the tapered strut to that of a uniform strut of the same material and strength and with similar transverse sections. Denote it by λ.

For the tapered strut

$$EId^2y/dx^2+Py=o$$

with both terms zero at $x=\pm l$, and by symmetry, y will be a polynomial in even powers of x.

The differential equation becomes

$$T^4y''+k^2y=o,$$

with $T=1$ at $X=0$ and y and EIy'' both zero at $X=\pm 1$.

§3. *y a polynomial of degree 2*

y is obviously $y_o(1-X^2)$ and $y''=-2y_o$. Hence at $X=1$, I must vanish and stress

failure would occur. Thus this case is only of academic interest but is included here as an approximation to the "calculus of variations" strut (a good approximation!) which also has zero area at the pins. We have $T^4/k^2 = -y/y'' = (1-X^2)/2$. Putting

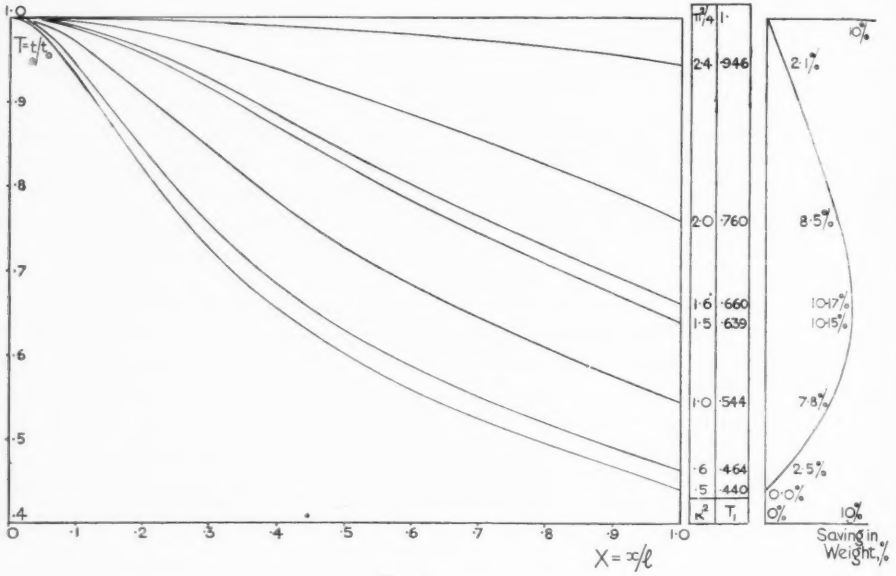


Fig. 1

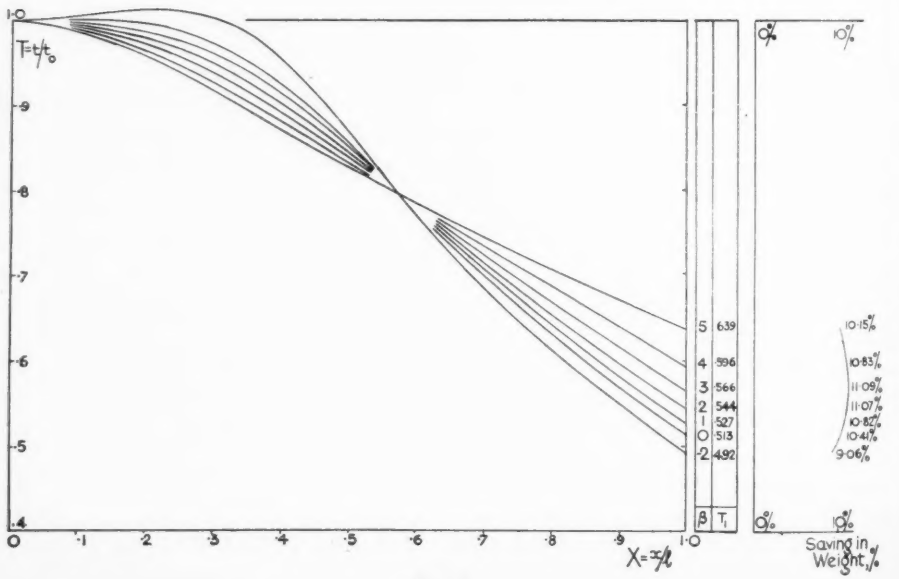


Fig. 2

$X=0$, $T=1$, we get $k^2=2$. The longitudinal profile is $t=t_o\ (1-X^2)^{1/4}$ and the value of λ is

$$\pi/2\int_0^1\sqrt{(1-X^2)/2}\,dX=\pi^2/8\sqrt{2}=0.8724$$

giving a theoretical saving of weight of 12.76 per cent. For the calculus of variations strut $k^2=\pi\sqrt{3}/4=1.8505$ and the theoretical saving of weight is 13.4 per cent.

§4. *y a polynomial of degree* 4

y could now be taken as

$$y_o(1-X^2)\ (1+\alpha X^2)$$

and α could be chosen to give any value of k, for putting $X=0$ we get $k^2=(-y''/y)_{x=0}$ $=2\ (1-\alpha)$; the approximation to the calculus of variations strut would be very close indeed if α were chosen to give k^2 about 1.85.

We are now, however, able to find a practical strut, for since y'' may be made to vanish at $X=1$, the transverse dimension there need not be zero.

We take $y''=-c\ (1-X^2)$ and integrate twice with even powers only and with $y=0$ at $X=1$.

$$\begin{aligned}y&=-cX^2/2+cX^4/12+\text{constant}\\&=c\ (1-X^2)/2-c\ (1-X^4)/12\\&=c\ (1-X^2)\ (5-X^2)/12\end{aligned}$$

Thus $T^4/k^2=(5-X^2)\ /12$. Putting $X=0$, $T=1$, we get $k^2=12/5$ and the longitudinal profile is given by $T=t/t_o=(1-X^2/5)^{1/4}$. Also

$$\lambda=(\pi/5/2\sqrt{12})\int_0^1\sqrt{(1-X^2/5)}\,.dX$$

which integrates easily and gives $\lambda=0.979$, a saving in weight of 2.1 per cent. The profile is shown in Fig. 1.

§5. *y a polynomial of degree* 6

Take

$$y''=-c\ (1-X^2)\ (1+\alpha X^2)=-c\ (1+\alpha-1\ X^2-\alpha X^4)$$

Integrating as before

$$\begin{aligned}y&=c\ [(1-X^2)/2+(\alpha-1)\ (1-X^4)/12-\alpha\ (1-X^6)/30]\\&=c\ (1-X^2)\left[\tfrac{1}{2}+\frac{\alpha-1}{12}-\frac{\alpha}{30}+\left(\frac{\alpha-1}{12}-\frac{\alpha}{30}\right)X^2-\frac{\alpha X^4}{30}\right]\end{aligned}$$

Hence

$$T^4/k^2=-y/y''=\left[\tfrac{1}{2}+\frac{\alpha-1}{12}-\frac{\alpha}{30}+\left(\frac{\alpha-1}{12}-\frac{\alpha}{30}\right)^{X2}-\frac{\alpha X^4}{30}\right]/(1+\alpha X^2)$$

When $X=0$, $T=1$, hence

$$1/k^2=(1/2)+(\alpha-1)/12-\alpha/30=5/12+\alpha/20$$

giving

$$T^4=\frac{1+(1-k^2/2)X^2-(12-5k^2)X^4/18}{1+(20/k^2-25/3)\ X^2}=(N/D,\ \S7).$$

and

$$\lambda=(\pi/2k)\int_0^1\sqrt{\frac{1+(1-k^2/2)X^2-(12-5k^2)X^4/18}{1+(20/k^2-25/3)X^2}}\,dX$$

Thus we may find one strut of this type for every k^2, and the profile is easily calculated from T^4 above. To find λ, however, a graphical or numerical method is required. The writer has used Simpson's rule throughout with ten strips, and as a check, the integral of §4 was similarly evaluated and found to give an error of 1 in 10,000.

A set of profiles is shown in Fig. 1 with the saving of weight possible. When $k^2=2$ the polynomial reduces to the quartic of §4.

§6. *y a polynomial of degree* 8

Take

$$y'' = -c(1-X^2)(1+\beta X^2+\gamma X^4) = -c(1+(\beta-1)X^2+(\gamma-\beta)X^4-\gamma X^6)$$

and integrate as before

$$y = c\left(\frac{1-X^2}{2}+\frac{(\beta-1)(1-X^4)}{12}+\frac{(\gamma-\beta)(1-X^6)}{30}-\frac{\gamma(1-X^8)}{56}\right)$$

and

$$\frac{T^4}{K^2} = \tfrac{1}{2}+\frac{(\beta-1)(1+X^2)}{12}+\frac{(\gamma-\beta)(1+X^2+X^4)}{30}-\frac{\gamma(1+X^2+X^4+X^6)}{56}$$

$$\overline{1+\beta X^2+\gamma X^4}$$

$$= \left(\tfrac{1}{2}+\frac{\beta-1}{12}+\frac{\gamma-\beta}{30}-\frac{\gamma}{56}\right)+\left(\frac{\beta+1}{12}+\frac{\gamma-\beta}{30}-\frac{\gamma}{56}\right)X^2+\left(\frac{\gamma-\beta}{30}+\frac{\gamma}{56}\right)X^4-\frac{\gamma X^6}{56}$$

$$\overline{1+\beta X^2+\gamma X^4}$$

and as $T=1$ when $X=0$,

$$\frac{1}{k^2} = \tfrac{1}{2}+\frac{\beta-1}{12}+\frac{\gamma-\beta}{30}-\frac{\gamma}{56} = \frac{5}{12}+\frac{\beta}{20}+\frac{13\gamma}{840}$$

Since β and γ are arbitrary, we can now have any given k^2 and satisfy one other condition in addition. For a given k^2, γ can be expressed in terms of β and k^2 and thence T^4 and λ found as functions of the parameter β. We get

$$T^4 = \frac{1+(1-k^2/2)X^2+(1-\overline{5+\beta}k^2/12)X^4-(15/13)(1-5/12+\beta/20)X^6}{1+\beta X^2+(840/13)(1/k^2-5/12+\beta/20)X^4} \quad (=N/D\ \S7).$$

$k^2=1.5$ has been chosen for the examples worked out in this case.

We get

$$T^4+\left(1+\frac{X^2}{4}+\frac{(3-\beta)X^4}{8}-\frac{9(5-\beta)X^6}{104}\right)\Big/\left(1+\beta X^2+\frac{42(5-\beta)X^4}{13}\right)$$

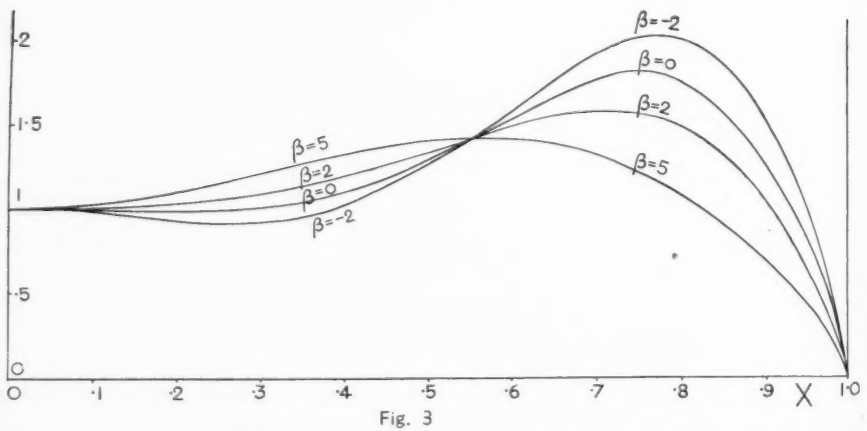


Fig. 3

$\beta=5$ gives that polynomial of §5 for which $\alpha=5$ and other struts have been dealt with for $\beta=4$, 3, 2, 1, 0 and -2. For the first five, the saving in weight is from over 10 per cent. to over 11 per cent. A " waist " in the profile is just developing when $\beta=0$ and this is quie pronounced when $\beta=-2$, yet the weight saved in the latter

case exceeds 9 per cent. It is evident that the form of taper may vary very much and yet save 10 or 11 per cent of the possible 13.4 per cent.

§7. *Stress failure*

The greatest stress, at any x, due to bending, is the product of (M/I) and the greatest t at the section, and is therefore equal to $(PyT/I)\,\tau$ where τ is the greatest t_o perpendicular to the neutral axis of the section at $x=0$. Hence the greatest bending stress at any

$$x = Py\tau/T^3 I_o = P\tau y^{1/4}(-y'')^{3/4}/I_o k^{3/2}.$$

Now if our expression for T^4 as the ratio of two polynomials be denoted by N/D, y varies as $N(1-X^2)$ and since when $X=0$, $N=1$ and $y=y_o$, therefore $y=y_o N(1-X^2)$.

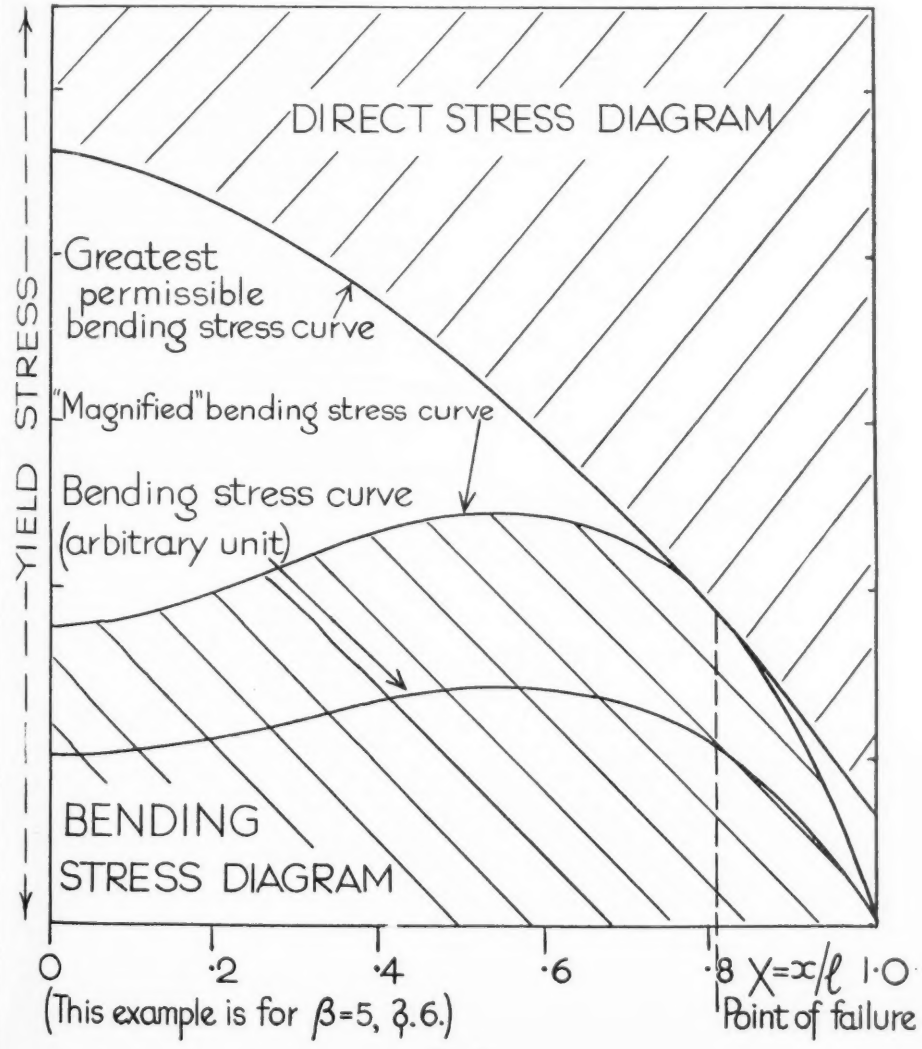


Fig. 4

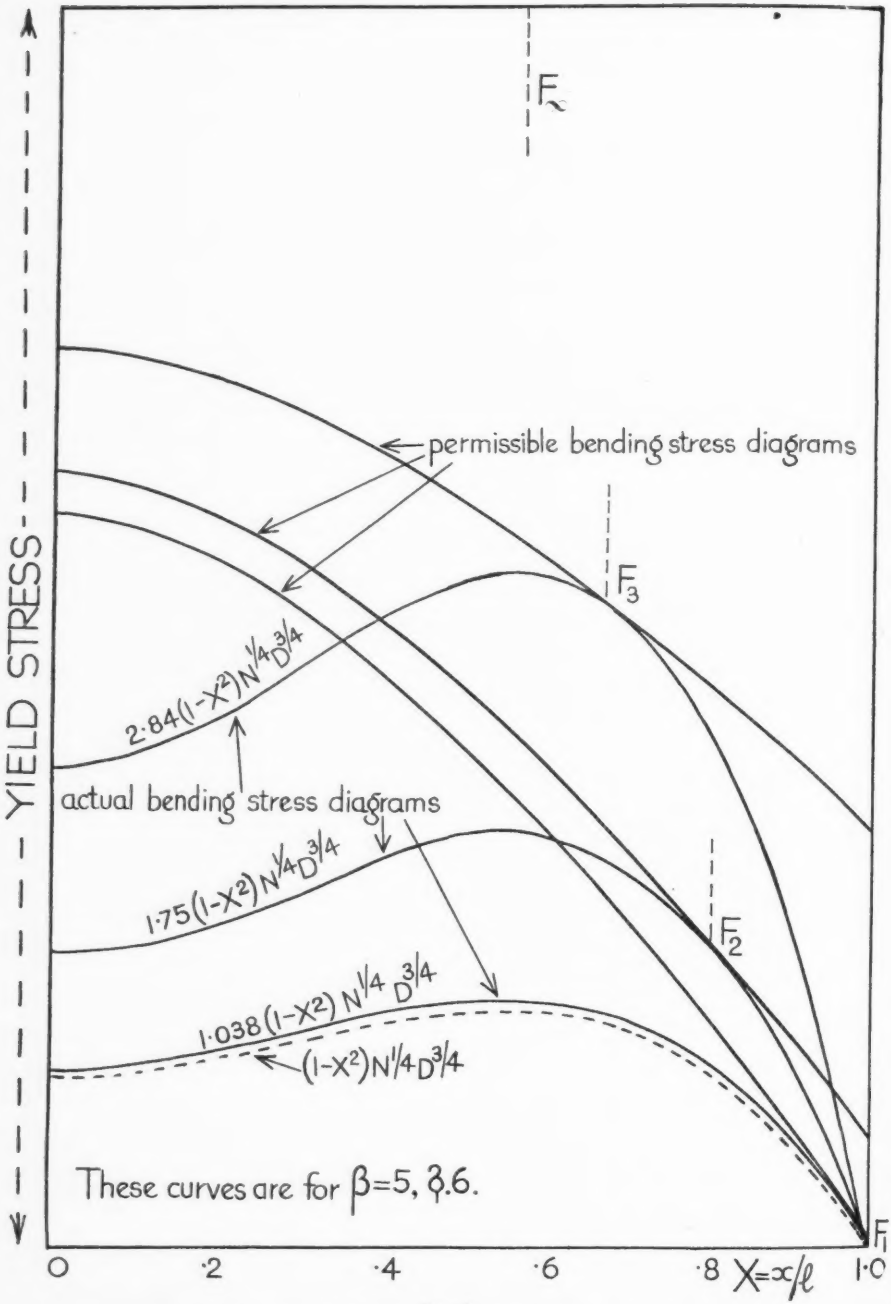


Fig. 5

F_1 failure at pin when P/A is equal to the yield stress.
F_2 point of failure for similar strut to carry same load but longer, 12/11.
F_3 ditto but longer in ratio 3/2.
F_∞ limiting position of point of failure, as length tends to infinity.

Also $T^4/k^2 = N/Dk^2 = y/(-y'')$ so that

$$-y'' = y_0 Dk^2 (1-X^2).$$

Therefore the greatest bending stress at any x is $Py_0 (1-X^2) N^{1/4} D^{3/4}/I_0$.

Since N and D have been evaluated in the course of the calculations, it is easy to evaluate $(1-X^2) N^{1/4} D^{3/4}$, and this is proportional to the greatest bending stress at any x for any one strut. Graphs of this function, showing how the greatest bending stress varies along the strut, are shown in Fig. 3 for four of the struts of §6.

If P/S is the yield stress (so that $S \leqq A_1$) then the greatest permissible bending stress at x or X is $P/S - P/A$; A is a multiple of T^2 which has been evaluated, so a graph of the greatest permissible stress is also easily drawn. A typical one (for $\beta = 5$) is shown in Fig. 4. When $S = A_1$ this curve will terminate on the X axis at $X = 1$. Now the bending stress can never exceed $P/S - P/A$, hence if the actual bending stress curve were superimposed on the same diagram as the permissible bending stress curve, the former which always has its $X = 1$ end at zero stress, could never be above the latter. Our graph of $(1-X^2) N^{1/4} D^{3/4}$ represents ordinates proportional to the actual bending stress, and if we " magnify " the ordinates (and the slope) in the same proportion until the " magnified " curve touches the permissible stress curve, the former then represents the greatest bending stress curve at the moment of stress failure. The required " magnification " can be found by trial. Thus we find with fair accuracy the value of X at the point of stress failure and from the expressions for the permissible stress and the actual bending stress, the value of y_0 at failure can be calculated (provided of course that $(y')^2$ is still negligible compared with unity). If $S = A_1$, the process of " magnification " goes on until the two curves have a common tangent at $X = 1$, i.e., stress failure occurs at the pin. The required " magnification " cannot be found with much accuracy by trial but is easily calculated by putting $X = 1 - Z$ and evaluating both functions to the first power of Z.

If now a similar but longer strut (same material and shape of section) be made to carry the same load, $1/A_1$ diminishes, $S < A_1$, and the point of failure moves towards the nearest turning point of the actual bending stress diagram, approaching that point as the length of the strut increases indefinitely. This movement of the point of failure is illustrated in Fig. 5 for struts whose lengths are in the ratio $1 : 12/11 : 3/2 : \infty$.

Further, the diagram with the magnified curve touching the permissible stress curve gives us the direct stress diagram and the bending stress diagram, at the moment of failure, Fig. 5.

STRESSES IN RING STRUCTURES

by

L. G. Whitehead, Ph.D.

Dr. L. G. Whitehead studied under Dr. N. A. V. Piercy, at Queen Mary College, obtaining his B.Sc.(Eng.) with 1st Class Honours. He obtained his Ph.D. in 1939. He is now a Lecturer in the aeronautical engineering department at Queen Mary College.

Introduction

THE simple ring frames which are a common feature of metal fuselage construction are being superseded in some large aircraft by more complicated frames in which one or more cross members are added to stiffen the frame. The stress distribution in simple rings is readily analysed by the standard methods for redundant structures, but the direct extension of these methods to more complicated cases leads normally to the solution of a number of simultaneous equations. The method now proposed avoids this difficulty by breaking down the calculation into a number of simple steps and then applying the principle of superposition to combine the results so obtained. In this respect it is equivalent to the Hardy Cross moment distribution method (1) or to Southwell's method of the systematic relaxation of constraints (2) though in many applications the final superposition of loadings is so simple that the full moment distribution or relaxation procedure is not required.

The usual assumptions adopted for stressing rings are retained in the present analysis. The most important of these are as follows: Only displacements due to bending are of importance; the distortion of an element of a curved bar is identical with that for a straight element of the same mean length and cross-section; and the deflections are small so that moments calculated on the basis of the undistorted shape are sufficiently accurate.

General Theory

Consider a ring frame (Fig. 1) consisting of three segments joining the points *A* and *B*, the three separate sections being rigidly

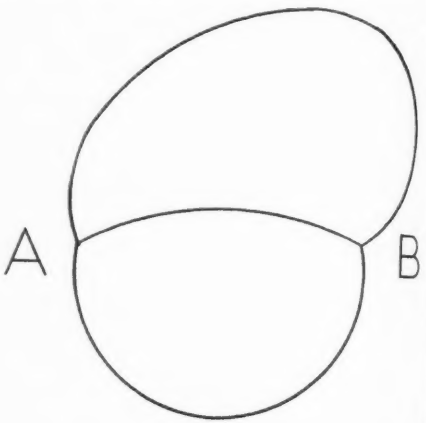


Fig. 1

attached to each other at their intersections. Initially the frame is assumed to be constrained against rotation and displacement at the points *A* and *B* and the external loads are then applied. The bending moments in each of the three segments are readily calculated under these conditions; the problem is in fact the familiar one of an arch built

Paper received July 16th, 1945.

in at either end. The end fixing moment for each segment and the force acting along AB are calculated and the algebraic sums give the constraining moments and forces which must be applied at A and B in order to maintain the initial configuration. The second step is to determine the moment which must be applied at A to the unloaded frame to produce unit rotation when B is held fixed. The corresponding load acting along AB which arises from the rotation at A is also required as it will cause a change in the horizontal constraining force. Similar calculations are required for the rotation of B with A fixed and for unit displacement of A relative to B along the line AB. In each of these stages the results for individual segments are calculated separately and then added together.

The final step of combining the particular solutions obtained is carried out by relaxing successively the angular constraints at A and B and the horizontal constraint fixing their relative positions. This will lead in each case to the reduction or elimination of the constraint that is relaxed coupled with secondary changes in the remaining constrains. The process is repeated until the constraining moments are reduced to negligible proportions.

The method may readily be extended to deal with more complicated rings with two or more internal members. Vertical constraints as well as horizontal and angular constraints arise at each intersection in such cases as these must be relaxed in the same way as the three constraints in the simpler example.

The procedure outlined above may be modified in detail, with advantage, in special cases. It becomes particularly simple if, as in many practical examples, the internal member is a straight bar connecting A and B. Then, since deflections due to axial loads are neglected, there is no displacement of A relative to B along AB and only the constraining moments and rotations at A and B have to be recorded. For frames symmetrical about a vertical axis it is convenient to consider the rotations at A and B simultaneously and to impose as separate operations either equal or equal and opposite rotations when relaxing the angular constraints at the two points. This procedure is followed in the next sections where the method is developed in detail for a symmetrical ring.

The Bending Moments in Symmetrical Encastré Curved Segments

It is convenient to consider each of the separate curved segments as a ring completed by a rigid straight member joining the ends A and B. The straight rigid member provides the required end conditions for the curved segment and if the moment, shear and axial loads are determined at the centre of the rigid bar full advantage is taken of the symmetry of the structure. The system of loads on one of the simple rings so formed consists of the loads on the curved segment together with reactions at A and B chosen so that the external forces are in equilibrium.

The equations for the unknown moment X_M, shear force X_S and axial load X_P at the mid-point of the rigid member are derived by the principle of virtual work. They are

$$\int \frac{M_o ds}{EI} + X_M \int \frac{ds}{EI} - X_P \int \frac{y ds}{EI} = 0,$$

$$-\int \frac{M_o y ds}{EI} - X_M \int \frac{y ds}{EI} + X_P \int \frac{y^2 ds}{EI} = 0,$$

and

$$\int \frac{M_o x ds}{EI} + X_S \int \frac{x^2 ds}{EI} = 0. \quad . \quad (1)$$

In these equations bending moments have been reckoned as positive when they tend to decrease the curvature of the segment and the positive directions for X_M, X_P and X_S are indicated in Fig. 2. M_o is the bending moment in the ring due to the external loads when cut at the centre of the

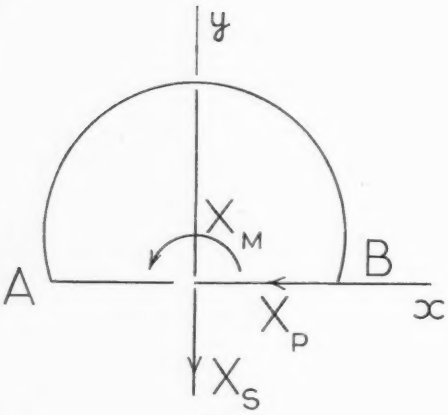


Fig. 2

rigid member. The integrals extend over the curved segment, there being no contribution from the straight member since it is assumed rigid. The unknowns are determined directly from the above equations, X_P is the horizontal thrust along AB and hence it is the contribution to the total horizontal constraint from the segment considered. The end fixing moments, *i.e.*, the constraining moments at A and B, are $X_M + bX_S$ and $-X_M + bX_S$, respectively, in an anti-clockwise direction (the length AB is equal to $2b$).

The equations simplify if the loading is symmetrical as well as he structure, for then

$$\int \frac{M_o x ds}{EI} = 0$$

and therefore X_S is zero. Simplifications also result if the loading is anti-symmetrical, *i.e.*, if the loads are equal for points situated symmetrically on either side of the centre line but act in opposite senses. In this latter case

$$\int \frac{M_o ds}{EI} = \int \frac{M_o y ds}{EI} = 0$$

so that both X_M and X_P are zero and there is only one unknown X_S. It is frequently convenient to make use of these results by splitting an asymmetrical loading into symmetrical and anti-symmetrical components (3).

The total constraining moments and forces are found by applying the equations successively to each segment of the ring.

Changes in Stress Distribution Due to Relaxation of Constraints

The distribution of load and the distortions under three separate loading conditions must be calculated before the relaxation of constraints can be carried out. The first and third cases correspond to the relaxation of the angular constraints at A and B without movement of A relative to B, while the second corresponds to displacement of A relative to B without rotation of the ring at these points.

The first case to be considered is that of a segment symmetrically loaded by equal and opposite end fixing moments (*i.e.*, one clockwise and the other anti-clockwise). The rotations of the ends, the variation of the bending moment around the segment and the horizontal force which arises due to the fact that the ends of the segment are at a fixed distance apart are all required for the solution of the problem. Suppose that equal end fixing moments M_1 are

Fig. 3

applied in the directions indicated in Fig. 3 and that the corresponding horizontal force is H; then the bending moment M at a general point will be

$$M = M_1 - Hy.$$

H may be determined by summing the virual work for all elements of the segment taking as distortions those which actually occur and employing for a system of loads in equilibrium unit horizontal load along

AB. The unit horizontal load will do no work since its points of application do not deflect, therefore

$$\int y\left[\frac{M_1 - Hy}{EI}\right]ds = 0.$$

Hence

$$H = M_1 \int \frac{yds}{EI} \Big/ \int \frac{y^2 ds}{EI} \quad . \quad (2)$$

and the moment M becomes

$$M = M_1\left[1 - y \cdot \frac{\int \frac{yds}{EI}}{\int \frac{y^2 ds}{EI}}\right] \quad . \quad (3)$$

The virtual work equation for unit moment applied to the segment gives the sum of the rotations at A and B and, since symmetry is assumed, these are numerically equal. Hence

$$2\theta_B - M_1 \int \left[1 - y \cdot \frac{\int \frac{yds}{EI}}{\int \frac{y^2 ds}{EI}}\right]\frac{ds}{EI} = 0,$$

so that

$$\theta_B = \frac{M_1}{2}\left[\int \frac{ds}{EI} - \frac{\left(\int \frac{yds}{EI}\right)^2}{\int \frac{y^2 ds}{EI}}\right] \quad . \quad (4)$$

The second problem involved in the elimination of the horizontal constraining force is dealt with in a similar manner. In this case the points A and B approach one another due to the application of a horizontal force H without the segment twisting at A and B. Unit moment applied to the segment gives the virtual work equation

$$\int \frac{(M_1 - Hy)}{EI} ds = 0,$$

since the ends do not rotate. Therefore the fixing moment arising at the ends due to their relative displacement is connected with the horizontally applied force H by

$$M_1 = H \int \frac{yds}{EI} \Big/ \int \frac{ds}{EI} \quad . \quad . \quad (5)$$

The virtual work equation for unit horizontal force now becomes, if the horizontal displacement is δ,

$$\delta + H \int y\left[\frac{\int \frac{yds}{EI}}{\int \frac{ds}{EI}} - y\right]\frac{ds}{EI} = 0,$$

so that δ is related to H by

$$\delta = H\left[\int \frac{y^2 ds}{EI} - \frac{\left(\int \frac{yds}{EI}\right)^2}{\int \frac{ds}{EI}}\right] \quad . \quad (6)$$

The relations given above are sufficient for the complete solution of problems involving symmetrically loaded rings. The third loading case indicated in Fig. 4 is required for asymmetrical loadings. It is the only one which arises if the loading is antisymmetrical for it is a feature of such loadings that H is always zero.

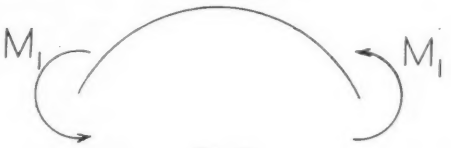


Fig. 4

The bending moment in the segment when there is no horizontal constraint is

$$M = M_1 x/b,$$

and it is readily verified that this system of moments does not give rise to any movement of A relative to B. The rotations at A and B are clearly equal so that the virtual work equation obtained by considering the actual distortions and a moment varying as x/b gives for this case

$$\theta_B = \frac{M_1}{2b^2}\int \frac{x^2 ds}{EI} \quad . \quad . \quad (7)$$

It will be noticed that all the integrals required in this section have occurred previously when determining the stress distribution in the loaded segments built in at A and B.

Numerical Example

The method will now be applied to a simple example which will demonstrate the main principles involved. The example considered is that of a doubly symmetrical

ring in which the outer members are three quarters of a complete circle and have one third the moment of inertia of the straight internal member joining them. The loading assumed comprises equal moments applied at each end of the straight member. In this case the external moments are balanced entirely by the constraining moments when A and B are held fixed so that the first and a more familiar step in the solution does not arise (*i.e.*, the calculation of the bending moment distribution in an encastré segment under external load). In addition, as the internal member is straight, no change can occur in the length AB. Hence the rotations required at A and B in order to liquidate the constraining moments can be determined directly without employing the successive steps involved in the complete moment distribution or relaxation methods.

The second step is to determine the end moments for unit twist at A and B in the members designated 1, 2 and 3 in Fig. 5.

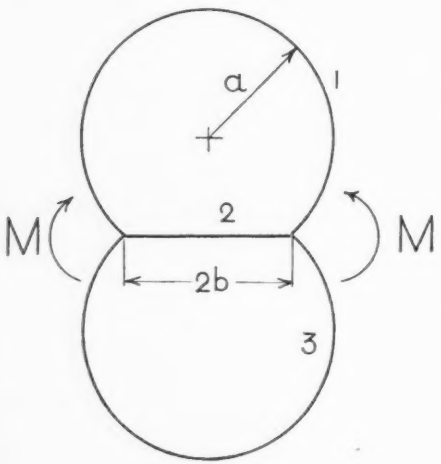


Fig. 5

Only the moments at one of these points need be recorded since the values at the other point are numerically equal. For the circular arc elements equations (2) and (4) are employed, the values of the integrals required being, for $\varphi = 3\pi/4$ (see Appendix),

$$\int ds = \frac{3\pi a}{2}$$

and

$$\int y\,ds = \sqrt{2}a^2\left(1+\frac{3\pi}{4}\right)$$

$$\int y^2 ds = \frac{3a^3}{2}(1+\pi).$$

Hence

$$\theta_B = \frac{M_1 a}{EI_1}\,.\,0.544,$$

or in terms of $I_2 = 3I_1$,

$$M_1 = 0.614\frac{EI_2\theta_B}{a}$$

The expression for M_3 is identical with that for M_1 as the dimensions of the members are the same. M_2 the moment carried by the straight member is related to the twist at the ends by

$$\theta_2 = \frac{M_2 b}{EI_2},$$

and as $a = b\sqrt{2}$

$$M_2 = 1.414\frac{EI_2\theta_B}{a}$$

Hence the proportion of the total moment M carried by the straight member AB is

$$\left(\frac{M_2}{M_1+M_2+M_3}\right)M = 0.535\,M.$$

The remainder is divided equally between the upper and lower arcs.

The moment in the upper segment is accompanied by a tension in AB given by eqn. (2) as

$$H_1 = 0.177\frac{M}{a}$$

But an equal compression arises from the lower segment so that there is no end load in AB. The value of H_1 is required, however, for the calculation of the bending moment distribution in the circular segments. The bending moment has the general value

$$M_1 - H_1 y = M\,[0.107 + 0.177\cos\theta].$$

At the highest point of the ring, where $\theta = \pi$, it is $-0.07\,M$ and at this point there is of course an axial force equal and oppo-

site to H_1, *i.e.*, a compressive load of $0.177\ M/a$.

The complete system of forces and moments acting at a cut along the axis of symmetry are indicated in Fig. 6. It may

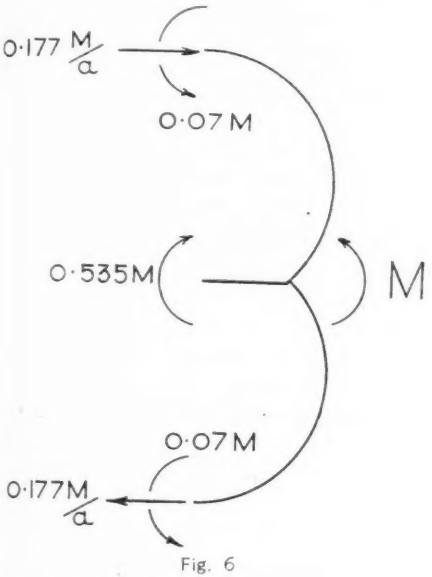


Fig. 6

readily be checked that these are equivalent to the externally applied moment M.

Appendix

Evaluation of Integrals for a Uniform Circular Segment

Consider a uniform circular arc segment of radius a subtending an angle 2ϕ at the centre (Fig. 7). The co-ordinates x and y of a point P measured from O are given in terms of the angle θ, which the radius vector CP makes with the downward vertical from the centre CO, by

$$x = a \sin \theta,$$

and

$$y = -a\,[\cos\phi + \cos\theta].$$

The integrals around the segment thus extend from $\theta = \pi - \phi$ to $\theta = \pi + \phi$. As the segment is assumed uniform the factor EI is

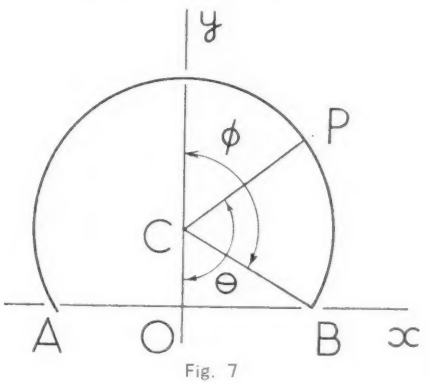


Fig. 7

constant and may be taken outside the integrals. The values required are therefore

$$\int ds = 2a\phi,$$

$$\int y\,ds = 2a^2\,[\sin\phi - \phi\cos\phi],$$

$$\int y^2 ds = a^3\,[2\phi\cos^2\phi + \phi - \tfrac{3}{2}\sin 2\phi],$$

and

$$\int x^2 ds = a^3\left[\phi - \frac{\sin 2\phi}{2}\right]$$

References

1. Hardy Cross—Analysis of Continuous Frames by Distribution of Fixed End Moments. Trans. Amer. Soc. Civil Engr., Vol. 96, p. 1 (1932).
2. R. V. Southwell—Stress Calculations in Frameworks by the Method of Systematic Relaxation of Constraints. Proc. Roy. Soc. A, Vol. 151, p. 56 (1935).
3. J. S. Newell—The Use of Symmetric and Anti-Symmetric Loadings. Jour. Aer. Sci., Vol. 6, p. 235 (1939).

RETARDATION EFFICIENCY OF SHOCK-ABSORBER AND ARRESTER GEAR

by

P. B. Walker, M.A., Ph.D.

P. B. Walker graduated in Mechanical Sciences at Cambridge in 1926. Following research under Sir Melville Jones, he obtained his Ph.D. in 1931. After working on the design staff of Armstrong Whitworth and Hawkers, he joined the R.A.E. in 1935, and is now head of the S.M.E. department.

Introduction.

The complexity of much of the mechanical gear used for shock absorption and arresting in aircraft engineering is apt to obscure some of the broad generalizations that may be deduced from the elementary principles of classical mechanics. More particularly does this apply to the distance required to arrest the motion of an aircraft or falling body when the retarding force must not exceed a specified value. This note merely presents some more or less self-evident truths which may be of some value in dealing with new landing and arrester problems.

It is not intended to limit this brief investigation to particular methods or applications of deceleration, but rather to concentrate on the fundamental principles common to all. The following concrete examples, however, are selected as representative and typical, for reference or illustration as and when appropriate.

(*a*) Landing gear for an aircraft.
(*b*) Horizontal arrester gear for an aircraft.
(*c*) Free dropping of supplies and equipment.
(*d*) Dropping by parachute.

In the problem of pure deceleration, without the complication of gravity force, the basic fact is that to stop a body without the deceleration exceeding a specified value requires a certain minimum distance, which distance corresponds to uniform deceleration. No amount of design ingenuity can override this fundamental law, so that a designer must always provide for a certain travel or stroke which depends only upon the initial velocity and the maximum deceleration that can be allowed.

Examination of the principles commonly used for producing deceleration then reveals a further law that from the point of view of the engineer is almost equally fundamental. In general, any practical system is likely to require an appreciably greater distance than the ideal minimum associated with uniform deceleration. This gives rise to the concept of "retardation efficiency" which is a criterion of merit where travel or stroke is a critical design consideration.

It is, however, seen to be not very difficult to prevent the retardation travel exceeding twice the ideal distance (efficiency 50%), which corresponds to a simple elastic system acting in direct compression and not preloaded. There are several ways in which this standard of retardation efficiency can be improved upon within limits. The two outstanding are pre-loading of elastic systems or the introduction of fluid resistance, both of which tend towards a more nearly uniform decelera-

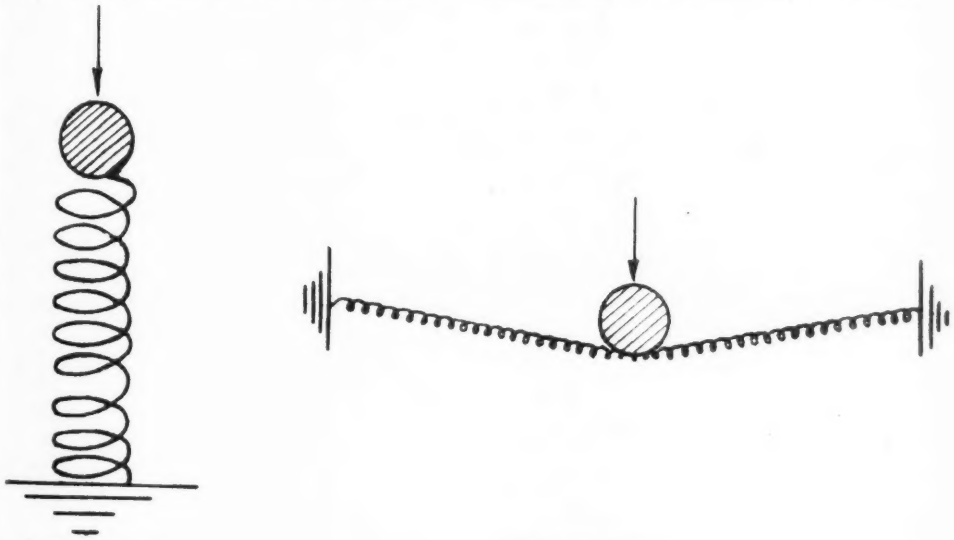
Paper received August, 1945.

tion, and hence a higher retardation efficiency (see Figs. 1 and 2).

On the other hand there is one type of deceleration system that must inevitably require a longer travel, and have a comparatively low retardation efficiency. This general classification embraces all kinds of nets, carpets, wires, etc., that are stretched at right angles to the direction of the motion to be arrested (Fig. 1b). Such systems (referred to as "lateral") are sometimes used for arresting falling bodies, for arresting horizontal motion of aircraft, and could conceivably be used as landing gear for aircraft.

Investigation shows that the highest retardation theoretically possible with such systems is 50%, and is then only approachable with a high initial tension and considerable flexibility. Thus any increase of tension as the body travels while being decelerated leads to a still further departure from the ideal of uniform deceleration. The extreme is an elastic wire just taut initially, for which the retardation efficiency falls to 25%, and therefore requires four times the theoretical ideal distance for pure deceleration without gravity.

The foregoing consideration of deceleration is concerned mainly with the mechanical and design difficulties of achieving a high retardation efficiency. It is necessary to remark, however, that were a near approach to be made to uniform deceleration, there might be conflict with other requirements. The initial build up of deceleration from zero, which so often obtains on conventional systems, is beneficial to mechanisms and structures susceptible to shock loads. On undercarriages, moreover, the same characteristic is often employed to reduce the maximum deceleration experienced in gentle landings, and to



1a Direct System. 1b Lateral System.

NOTE.—In both cases the resistance represented by a spring may be produced by the following alternatives or combinations of them.

(a) Unloaded Spring or Equivalent.
(b) Pre-loaded Elastic Resistance.
(c) Fluid Resistance.
(d) Frictional Resistance.
(e) Resistance produced by Plastic Deformation.

Fig. 1

Basic Systems for Deceleration.

give the pilot a physical impression of the severity of ground impact. Thus the conclusion is reached that, whilst for some purposes the highest possible retardation efficiency may be justifiably the aim, some compromise might become necessary in special cases.

order of 3g or 4g usually applicable to aircraft, if the retardation efficiency appropriate to pure deceleration is low. The lateral systems (nets, wires, etc.) are particularly at a disadvantage in this respect, even when a reasonably large travel is permissible. It can,

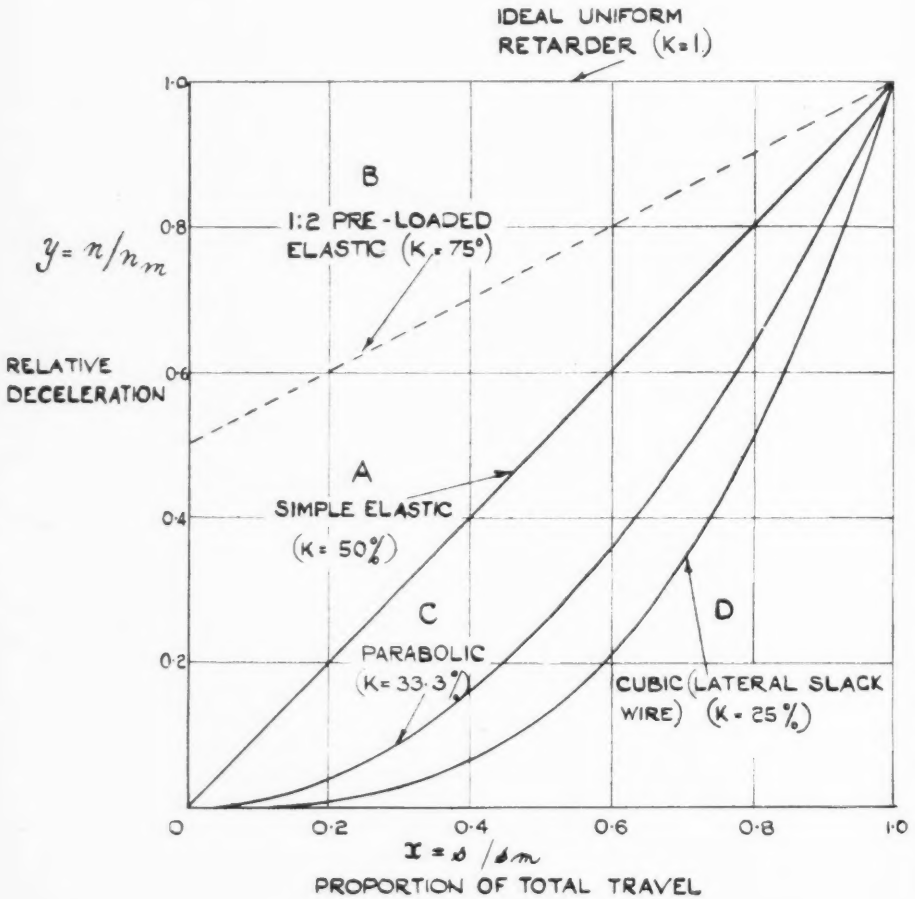


Fig. 2

Characteristic Deceleration Curves and Retardation Efficiency (K).

When gravity force acts in the direction of deceleration, the problem becomes rather more complicated and generalizations more difficult. The effect is not serious where high decelerations are normally employed. It can become very serious for decelerations of the

in fact, become completely impossible to arrest the motion without the maximum allowable deceleration being exceeded where this value and the retardation efficiency are comparatively low.

1. *Main parameters.* The three main parameters are as follows:—

(*a*) The initial velocity (V), conveniently represented by the equivalent free height drop (s_1) in vacuo, *i.e.*, $s_1 = V^2/2g$.*

(*b*) The retarding force (P), conveniently represented by the deceleration coefficient n, with maximum value n_m.

(*c*) The displacement (s) during the period of deceleration, with s_m the total distance to rest.

2. *Gravity absent.* With a constant applied retarding force, and no gravitational force, the total travel (s_m) may be expressed,

$$s_m = s_1/Kn_m \quad . \quad . \quad (1)$$

where K is unity for uniform deceleration and otherwise a coefficient less than unity depending upon the characteristics of the shock absorbing or arrester system. By equating the initial kinetic energy to the work done against the retarding force the value of K is readily shown to be given by

$$K = \int_0^1 y\,dx \quad . \quad (2)$$

where $x = s/s_m$ and $y = n/n_m$

3. *Retardation efficiency.* The coefficient K may conveniently be regarded as an efficiency factor from the standpoint of bringing the aircraft or other body to rest in the minimum distance consistent with not exceeding the maximum allowable retarding force. Although varying with different designs of shock-absorbing and arrester gear, its range of variation is limited by practical engineering considerations. For many purposes, moreover, its approximate value only needs to be known.

A selection of theoretical curves is shown in Fig 2. The corresponding values of retardation efficiency (K) are also indicated, these being simply the areas under the respective curves.

4. *Direct compression systems.* The simple elastic shock-absorbing or arrester system, such as a directly loaded compression spring (Fig. 1a) corresponds to the straight line (A) through the origin in Fig 2, for which the retardation efficiency is 50%.

In general, this simple elastic case represents the lower limit of efficiency for any system employing direct compression or tension, including conventional designs of undercarriage. Usually a higher efficiency is desirable. In theory this may be achieved by having a very flexible and pre-loaded spring, so that the retarding force is initially high and does not increase appreciably during the period of deceleration. Thus pre-loading to half the final value (line B in Fig. 2) increases the retardation efficiency from 50% to 75%. To some extent this principle is employed on a conventional oleo undercarriage by the initial air compression or pre-loading of springs.

On a conventional oleo undercarriage an increase of retardation efficiency is also obtained by combining viscous fluid resistance with elastic resistance. Since the fluid resistance is highest initially when the velocity is high, its combination with fluid resistance gives a more nearly uniform deceleration.

Other possible methods make use of friction or plastic resistance. In theory both could be made to give a uniform deceleration, but there are many practical difficulties. A typical example of friction retardation is the winch and friction drum which might be used for horizontal arresting. The best example of plastic resistance is the crash-pan used for parachuted bodies, which is simply a light structure that is completely crushed on impact. Devices combining both friction and plastic resistance have also been employed with some success for special purposes.

5. *Lateral systems.* The curves below the "elastic" line in Fig. 2 correspond to the less efficient systems. The curve (C) for parabolic

* The following table may be useful:—

V (ft./sec.)	8	10	12	14	15	16
s_1 (feet) .	1.00	1.55	2.24	3.04	3.50	3.97

variation has a retardation efficiency of 33.3%, and that for cubic variation (D) has a value as low as 25%.

A typical system having retardation efficiency of this order is an elastic (or elastically supported) wire stretched at right angles to the direction of motion to be arrested (Fig. 1b). This may be regarded as representative of various alternative systems working on the same principle, such as elastic carpets and nets.

In the somewhat extreme case where such a wire is highly tensioned and has a low elastic modulus, the retardation efficiency may readily be shown to be 50%*. The retarding force is attributable to the inclination given to the two portions of the wire, and the tension is assumed constant during the period of deceleration.

At the other extreme is a wire just taut and with no initial tension. Here the retarding force is attributable to the components of tension acquired as the wire stretches. The appropriate curve of deceleration is then the cubic in the figure, for which the retardation efficiency is only 25%*.

In practice some intermediate condition would probably occur, such as the parabola in Fig. 2 with retardation efficiency 33%. For the general type of "lateral" shock-absorbing or arrester system, however, 50% represents the upper limit of efficiency attainable by all ordinary means, contrasting with simple "direct" systems for which 50% is in general the lowest possible value.

It is important to remark that for pure deceleration a low retardation efficiency (*i.e.*, long travel) may not always be seriously detrimental to these "lateral" systems, particularly when they are installed on the ground; but this conclusion needs to be taken with some reservation until the effects of gravitational force have been considered.

6. *Retardation with gravity.* The effect of full gravitational force is readily obtained by adding the total travel (s_m) to the equivalent free height drop (s_1) in the original equation (1), the coefficient K retaining its original meaning. The new equation for s_m then becomes: —

$$s_m = \frac{s_1}{Kn_m - 1} \quad . \quad . \quad (3)$$

The criterion for effective retardation when the full force of gravity opposes the retarding force is thus: —

$$N = Kn_m - 1 \quad . \quad . \quad (4)$$

which is the equivalent uniform deceleration coefficient with gravity absent on the basis of the same distance to rest. It is clear from the form of this criterion that gravitational force increases the importance of retardation efficiency, particularly when the maximum allowable deceleration is low. Thus it is not impossible for this criterion to become zero or negative, whereupon the body cannot possibly be arrested without the prescribed maximum deceleration being exceeded.

7. *Direct systems with gravity.* When the maximum allowable deceleration is high, as it may be for bodies dropped on to the ground, the effect of gravity is not likely to be at all serious. With maximum deceleration of the order used for aircraft (3 or 4g), and the retardation efficiencies of the order to be expected from "direct" decelerating systems, it is still not likely to be critical. The benefits of small increases in retardation efficiency or of maximum allowable deceleration, however, are disproportionately high in terms of reduced travel.

In the case of the conventional oleo undercarriage the retardation efficiency is usually reasonably high, and both the undercarriage and aircraft structures are designed for a deceleration of at least 3g. There has to be borne in mind also that on a conventional aircraft (and parachuted bodies) gravity force is counteracted to some extent by the aerodynamic lift forces. Horizontal arrester systems, of course, are not appreciably affected by gravity force at all.

8. *Lateral systems with gravity.* When the lateral systems mentioned above are used to

* To the first approximation.

arrest vertical motion within the 3 or 4g deceleration limit usually allowed for an aircraft, there is a real danger of the criterion $Kn_m - 1$ becoming small or even negative*. When such systems are installed on the ground a reasonably long travel may be acceptable, but there is clearly a danger of its exceeding all reasonable proportions or of vertical arresting becoming completely impracticable within the limits of deceleration imposed.

Should elastic wires, carpets or nets be used for arresting the descent of bodies not capable of withstanding high acceleration, therefore, considerable attention would need to be given to the problem of achieving the highest possible retardation efficiency. One suggestion is that the tension should be as high as is practicable and the flexibility as low as is practicable, so that the retardation efficiency is as near as possible to the 50% ideal for this type of system.

9. *Other considerations.* The foregoing takes no account of possible disadvantages that might accrue if attempts to achieve a high retardation efficiency were completely successful. For many purposes the highest possible retardation is a legitimate aim, but for others some compromise may be necessary, since there may be a conflict in requirements.

The need for compromise is most apparent on an aircraft undercarriage. On the conventional undercarriage system the deceleration builds up from zero over an appreciable travel. This is detrimental to retardation efficiency, but obviously beneficial to mechanisms and structures susceptible to shock loads. The tyres are an important safeguard in this respect, over and above any appropriate characteristics of the shock-absorbing mechanism proper.

The initial build up from zero also serves another purpose on undercarriages operating wholly or in part by elastic resistance. It provides the means of reducing the maximum deceleration occurring on gentle landings when the impact velocity is well below the maximum design figures. Thus the associated reduction in stroke limits the applied retarding force.

This is a useful characteristic of elastic decelerators with low initial loading, but the method of obtaining it is inefficient. In principle the best solution would be a system which always utilized the full stroke and maintained the same characteristic curve of deceleration, but automatically adjusted the scale of deceleration to suit the impact velocity. This principle is employed in an appreciable degree on a conventional oleo system.

* A maximum deceleration of $4g$ and retardation efficiency of 25% or $3g$ and $33\frac{1}{3}$% are not improbable combinations which give zero for the criterion $Kn_m - 1$.

REVIEW

The Aircraft Engineer's "A" Licence.
Group Capt. G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S. Newnes, Ltd., London. 1945. 17/6.

Upon the Licensed Aircraft Engineer will come an increasing responsibility as flying becomes the world means of transport. The fullest understanding of what the word responsibility implies can only come from knowledge and experience.

Knowledge is all important to the licensed aircraft engineer for he cannot afford to profit by the mistakes of experience. He must, indeed, make no mistake, and that statement alone is a measure of the great responsibility which lies upon his shoulders.

Group Captain Williamson is a first-class engineer, who has worn the mantle of responsibility with such an air of insouciance that it is liable to mislead those who do not know his great ability. This book is an instruction book for the Air Registration Board Examinations for the "A" licence. It is a most excellent work to drive through the questions set and any driver who fails to make the journey after the instructions given him by the author may as well decide that the responsibility for the safety of aircraft is not one he should undertake.

The foregoing comment does not mean that this is the only book which the prospective licensed aircraft engineer need buy, as the author is quick to point out in its preface. Throughout the most careful references are given to books which will give all the detailed information necessary. No one book, indeed, could contain it without being unnecessarily bulky.

The following are the chapter headings of the book under review:—1, Duties, responsibilities and requirements. 2, Aircraft licences. 3, Measuring and checking. 4, Construction of light airframes. 5, Erection of light aircraft. 6, Construction and inspection of large aircraft. 7, Control surfaces and controls. 8, Landing gear. 9, Hydraulics. 10, Instruments. 11, Automatic pilots. 12, Electrical and other accessories. 13, Maintenance and inspection. 14, Faults, adjustments and minor repairs. 15, Examination subjects other than aircraft maintenance.

Each chapter is followed by recommended books to read and a series of questions on the information given in the chapter. Nor are these questions simple to answer unless the chapter has been really studied. The reviewer casually looked through the chapter on landing gear to see what answer there was to the question "Is there any reason why an aircraft should pull to one side when taxying, although all brake adjustments turn out to be satisfactory?" He finally had to read the chapter through carefully to find out the *cause*, but not the *reason*. Even Group Captain Williamson, excellent writer though he is, nods occasionally in English.

A good book, well written, printed and illustrated.

AN APPRECIATION

The Council of the Royal Aeronautical Society wish to thank the following Companies who, by their generous co-operation, have done so much to help in the production of the Journal in its new form.

MARSTON EXCELSIOR LIMITED

MILES AIRCRAFT LIMITED

MESSIER AIRCRAFT EQUIPMENT LIMITED

HENRY MILLER & COMPANY

METALASTIK LIMITED

MOLLART ENGINEERING COMPANY LTD

THE MOND NICKEL COMPANY LTD.

THE PALMER TYRE LIMITED

'First in the Air'

Palmer

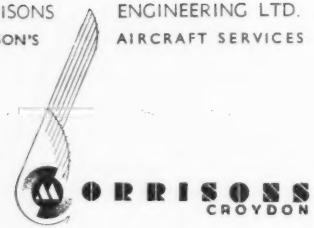
THE PALMER TYRE LIMITED
Herga House, Vincent Square, London, S.W.1.

MONOCHROME LIMITED

PARNALL AIRCRAFT LIMITED

MORRISONS
MORRISON'S

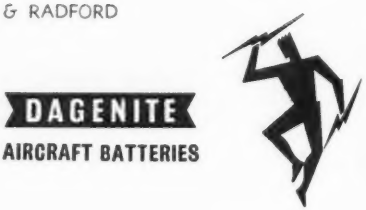
ENGINEERING LTD.
AIRCRAFT SERVICES



PERCIVAL AIRCRAFT LIMITED

D NAPIER & SON LIMITED

PETO & RADFORD



NITRALLOY LIMITED

PHILIDAS LIMITED

PHOTOSTAT LIMITED

PHOTOSTAT

RANSOMES, SIMS & JEFFERIES LTD.

Ransomes

EQUIPMENT FOR AERODROME
PREPARATION AND MAINTENANCE

SIR ISAAC PITMAN & SONS LIMITED

Pitman
AERONAUTICAL
PUBLISHERS

REYNOLDS TUBE CO., LTD.

REYNOLDS TUBE CO. LTD.
REYNOLDS ROLLING MILLS LTD.

REYNOLDS

LIGHT ALLOY PRODUCTS
COLD DRAWN SEAMLESS STEEL TUBES
AND FABRICATED TUBULAR STRUCTURES

PORTSMOUTH AVIATION, LIMITED

PORTSMOUTH AVIATION

R.F.D. COMPANY LTD.

R·F·D LTD
COMPANY

PRESSED STEEL CO., LTD.

PRESTCOLD
Refrigeration

A. V. ROE & COMPANY, LIMITED

AVRO

PYE LIMITED

PYE

RADIO . TELEVISION
TELECOMMUNICATIONS

ROLLS-ROYCE LIMITED

ROLLS ROYCE

S. GRAHAME ROSS LTD.

SAUNDERS-ROE LTD.

ROTAX LTD

ROTAX

SELF-PRIMING PUMP AND ENGINEERING CO., LTD.

ROTOL LIMITED

SERCK RADIATORS LIMITED

SERCK

L. A. RUMBOLD & CO., LTD.

RUMBOLD

SHORT BROTHERS (ROCHESTER & BEDFORD) LIMITED

SHORT BROTHERS
(Rochester & Bedford) Ltd.

SANGAMO WESTON LTD.

SIMMONDS AEROCESSORIES LTD.

SIMMS MOTOR UNITS LTD.

Simms
MAGNETOS

STERLING METALS LTD

STERMET
REGD TRADE MARK

SMITHS AIRCRAFT INSTRUMENTS LTD.

SMITHS

TAYLORCRAFT AEROPLANES (ENGLAND) LIMITED

THE STEEL
TAYLORCRAFT
AUSTER
AEROPLANE
THE EYES OF THE ARMY

THE SPERRY GYROSCOPE COMPANY LTD.

SPERRY

THE TECHNOLOGICAL INSTITUTE OF GREAT BRITAIN

GTI
COURSES FOR THE EXAMINATIONS
OF THE
ROYAL AERONAUTICAL SOCIETY

M. E. STACE & CO., LTD.

Stayco
SYNTHETIC RUBBER COMPONENTS
SEAL—WITH STAYCO RINGS

TITANINE LIMITED

TITANINE
DOPE

STANDARD TELEPHONES & CABLES LTD.

Standard
Radio

TUBES LIMITED

tubes limited

ERNEST TURNER GROUP

Ernest Turner (London), Ltd.
Ernest Turner (Weaving), Ltd.
Ernest Turner Electrical Instruments, Ltd.
Chas. Dould & Son, Ltd.

VOKES LTD.

TURNER MANUFACTURING COMPANY LIMITED

WADKIN LTD.

THE UNITED STEEL COMPANIES LIMITED

"FLYING FOX" ELECTRIC STEELS

S. FOX & CO. LTD. SHEFFIELD

WARWICK AVIATION COMPANY LTD.

VICKERS-ARMSTRONGS LIMITED

WESTLAND AIRCRAFT LIMITED

CHAS. WESTON & CO., LTD.

WESTON
OIL RETAINERS

WILLIAMSON MANUFACTURING CO., LTD.

A. C. WICKMAN LIMITED

A.C. Wickman LIMITED
• COVENTRY • ENGLAND •
SPECIALISTS IN MACHINE TOOLS & SMALL TOOLS FOR THE AIRCRAFT INDUSTRY

WORCESTER WINDSHIELDS AND CASEMENTS LIMITED

Worcester Windshields Sheet Metal Engineering

HENRY WIGGIN & COMPANY LTD.

For High Quality
NICKEL ALLOYS

YORKSHIRE ENGINEERING SUPPLIES LTD.

BRONZE FOUNDRIES
YESEATONIA
BEARINGS AND BUSHES

WILKINSON RUBBER LINATEX LTD.

NOVATEX
WILKINSON PRODUCT

THE YORKSHIRE PATENT STEAM WAGON CO.

YORKSHIRE
PATENT STEAM WAGON Co

DIRECTORY OF ADVERTISERS

Accles & Pollock Ltd.	Paddock Works, Oldbury, Birmingham	*Broadwell* 1500
AC-Sphinx Sparking Plug Co. Ltd.	Dunstable, Beds.	*Dunstable* 360
Aeraspray Mfg. Co. Ltd.	Thimble Mill Lane, Birmingham, 7	*Birmingham East* 1671 (*all lines*)
"The Aeroplane"	Bowling Green Lane, London, E.C.1	*Terminus* 3636
Aeroplane & Motor Aluminium Castings Ltd.	Wood Lane, Erdington, Birmingham	*Erdington* 2207-8-9
Aircraft Production	Dorset House, Stamford Street, London, S.E.1	*Waterloo* 3333
Airspeed Limited	The Airport, Portsmouth	*Portsmouth* 74631 (8 *lines*)
Alvis Limited	Holyhead Road, Coventry	*Coventry* 5501
Geo. Angus & Co. Ltd.	Angus House, 152-158 Westgate Road, Newcastle-upon-Tyne, 1	*Newcastle-upon-Tyne* 22656 (4 *lines*)
Armstrong Siddeley Motors Limited	Parkside, Coventry	*Coventry* 4061
Sir W. G. Armstrong Whitworth Aircraft Ltd.	Whitley, Coventry	*Coventry* 61061-4
The Automatic Coil Winder & Electrical Equipment Co. Ltd.	Winder House, Douglas Street, London, S.W.1	*Victoria* 3404-8 (5 *lines*)
Automotive Products Company Ltd.	Tachbrook Road, Leamington Spa	*Leamington Spa* 1700
Avimo Ltd.	Taunton, Somerset	*Taunton* 3634
Bakelite Limited	18 Grosvenor Gardens, London, S.W.1	*Sloane* 9911
Beckett, Laycock & Watkinson, Ltd.	Acton Lane, London, N.W.10.	*Elgar* 5403
	Factories: Uxbridge, Middlesex	*Uxbridge* 1111
T. M. Birkett & Sons Ltd.	Thomas Street, Hanley, Stoke-on-Trent	*Stoke-on-Trent* 2184
Blackburn Aircraft Ltd.	Brough, E. Yorks.	*Brough* 121
James Booth & Company Ltd.	Argyle Street Works, Nechells, Birmingham, 7	*Birmingham East* 1221
Boulton Paul Aircraft Ltd.	Wolverhampton, Staffs.	*Fordhouses* 3191
The Bristol Aeroplane Company Ltd.	Filton House, Bristol	
British Aluminium Co. Ltd., The	Salisbury House, London Wall, London, E.C.2	*Clerkenwell* 3494
The British Aviation Insurance Company Ltd.	3-4 Lime Street, London, E.C.3	*Mansion House* 0444 (6 *lines*)
British Ermeto Corporation Ltd.	Beacon Works, Hargrave Road, Maidenhead, Berks.	*Maidenhead* 2271
The British Parachute Company Ltd.	Trinity Street, Cardiff	*Cardiff* 8735-6-7
British Plastics	Dorset House, Stamford Street, London, S.E.1	*Waterloo* 3333
British Ropes Limited	52 High Holborn, London, W.C.1	*Chancery* 8822
British Thomson-Houston Co. Ltd. (The)	Lower Ford Street, Coventry	*Coventry* 4104
British Wire Products Ltd.	Worcester Road, Stourport-on-Severn	*Stourport* 240
J. Brockhouse & Co. Ltd.	Victoria Works, Hill Top, West Bromwich	*Wednesbury* 0243

The Brooke Tool Manufacturing Co. Ltd.	Warwick Road, Greet, Birmingham, 11	*Birmingham Victoria* 2323 (10 lines)
Broom & Wade Ltd.	High Wycombe, Bucks.	*High Wycombe* 1630 (8 *lines*)
Brown Brothers (Aircraft) Ltd.	Great Eastern Street, London, E.C.2	*Bishopsgate* 7654 (33 lines)
David Brown & Sons (Huddersfield) Ltd.	Huddersfield	*Huddersfield* 3500 (7 *lines*)
The Bushing Company Limited	Head Office: Hebburn-on-Tyne London Office: Imperial House, Kingsway, W.C.2	*Hebburn* 32241 *Temple Bar* 9584
Butlers Limited	Atlantic Works, Grange Road, Small Heath, Birmingham, 10	*Victoria* 2164-5-6
Callender's Cable & Construction Co. Ltd.	Hamilton House, Victoria Embankment, London, E.C.4	*Central* 5241
The Chloride Electrical Storage Co. Ltd.	Exide Works, Clifton Junction, near Manchester	*Swinton* 2011
Charles Churchill & Co., Ltd.	Coventry Rd., South Yardley, Birmingham	*Acocks Green* 2281
Cooper & Co. (B'ham) Ltd.	53 Little King Street, Birmingham, 19	*Northern* 2194-5
Crown Welding Co. Ltd.	Castle Hill, Douglas, Isle of Man	*Douglas* 199
The de Havilland Aircraft Co. Limited	Hatfield Aerodrome, Herts.	*Hatfield* 2345
Delco-Remy & Hyatt Ltd.	111 Grosvenor Road, S.W.1	*Victoria* 6242 (7 *lines*)
Dowty Equipment Limited	Cheltenham, Glos.	*Cheltenham* 53471
Dunford & Elliott (Sheffield) Ltd.	Attercliffe Wharf Works, Sheffield, 9	*Sheffield* 41121-2-3-4
Dunlop Rubber Co. Ltd.	Fort Dunlop, Erdington, Birmingham, 24.	*Erdington* 2121
English Steel Corporation Ltd.	Vickers Works, Sheffield	*Sheffield* 41071 (13 *lines*)
The Fairey Aviation Company Ltd.	Hayes, Middlesex.	*HAYes* 1800
Ferodo Limited	Chapel-en-le-Frith, Stockport.	*Chapel-en-le-Frith* 250
Thos. Firth & John Brown Ltd.	Atlas & Norfolk Works, Sheffield, 1.	*Sheffield* 20081 (10 *lines*) 26491 (6 *lines*)
Firth-Vickers Stainless Steels Ltd.	Staybrite Works, Sheffield	*Sheffield* 41193
Flight Publishing Co. Ltd.	Dorset House, Stamford Street, London, S.E.1	*Waterloo* 3333
Flight Refuelling Limited	Pickersleigh Road, Malvern Link, Worcs.	*Malvern* 1481
Folland Aircraft Ltd.	Hamble, Southampton, Hants.	*Hamble* 3191
General Aircraft Ltd.	The London Air Park, Feltham, Middlesex	*Feltham* 3636 (12 *lines*)
Gillett Stephen & Co. Ltd.	Atlas Works, Great Bookham, Leatherhead, Surrey	*Bookham* 2727 (4 *lines*)
Girling Limited	Garrison Lane, Birmingham, 9	*Victoria* 2951
Gloster Aircraft Co. Ltd.	Gloster Works and Aerodrome, Hucclecote, Glos.	*Gloucester* 6294 (18 *lines*)
Graviner Manufacturing Company Ltd.	16 Bassett Gardens, Osterley, Isleworth, Middlesex	*Hounslow* 1218
	Graviner Works, Gosport Road, near Fareham, Hants.	*Gosport* 89175-6-7

DIRECTORY OF ADVERTISERS

Handley Page Ltd.	Cricklewood, London, N.W.2	*Gladstone* 8000
Hawker Aircraft Ltd.	Canbury Park Road, Kingston-on-Thames	*Kingston* 1044 *Slough* 23861
Healthguard Aeroquipment	Woodbridge Road, Leicester.	*Leicester* 61228
Helliwells Ltd.	Old Town, Stratford-on-Avon	*Stratford-on-Avon* 3265
The Heston Aircraft Co. Ltd.	Heston Airport, Middlesex	*Southall* 2321
Heywood Compressor Co. Ltd.	Glover Street, Redditch, Worcs.	*Redditch* 743
Hiduminium Applications Ltd.	95 Farnham Road, Slough, Bucks.	*Slough* 20409
High Duty Alloys Ltd.	89 Buckingham Avenue, Slough, Bucks.	*Slough* 21201
H. M. Hobson (Aircraft & Motor) Components Ltd.	Hobson Works, Holbrook Lane, Coventry	*Coventry* 88671 (3 *lines*)
S. Hubbard Limited	Regent Mill, Luton, Beds.	*Luton* 2076
F. A. Hughes & Co. Ltd.	Metals Dept., Abbey House, Baker Street, London, N.W.1	*Welbeck* 2332-6
Henry Hughes & Son Ltd.	Husun Works, New North Road, Barkingside, Essex	*Hainault* 2601
The Hughes-Johnson Stampings Ltd.	Langley Green, Birmingham	*Broadwell* 1361 (3 *lines*)
Hunting Aviation Limited	P.O. Box 4, Caernarvon, N. Wales	*Caernarvon* 580 (4 *lines*)
Imperial Chemical Industries Ltd.	London, S.W.1	*Victoria* 4444
Integral Ltd.	Power Road, Chiswick, London, W.5	*Chiswick* 1539 *Chiswick* 3323
Irving Air Chute of Great Britain Ltd.	Icknield Way, Letchworth, Herts.	*Letchworth* 888
Jablo Propellers Limited	Mill Lane, Waddon, Croydon, Surrey	*Croydon* 2201 (4 *lines*)
Walter W. Jenkins & Co. Ltd.	31 St. Paul's Street North, Cheltenham	*Cheltenham* 53254
K.D.G. Instruments Ltd.	Purley Way, Croydon, Surrey	*Thornton Heath* 3868
Kelvin, Bottomley & Baird Ltd.	Kelvin Avenue, Hillington, Glasgow S.W.2	*Halfway* 3331
	Kelvin Works, Basingstoke	*Basingstoke* 690
K.L.G. Sparking Plugs Ltd.	Putney Vale, London, S.W.15	*Putney* 2671 (4 *lines*)
Langley Alloys Ltd.	Langley, Slough, Bucks.	*Langley* 262-3
Arthur Lee & Sons Ltd.	Crown Steel and Wire Mills, Bessemer Road, Sheffield, 9	*Attercliffe* 41144-5-6-7-8
	Mowbray House, Norfolk Street, London, W.C.2	*Temple Bar* 7187-8
	155 Church Lane, Handsworth Road, Birmingham, 20	*Northern* 2116-7
Leytonstone Jig & Tool Co. Ltd.	606 High Road, Leyton, London, E.10	*Leytonstone* 5022-3
Light-Metal Forgings Ltd.	Oldbury, Birmingham	*Broadwell* 1152
Lodge Plugs Limited	Rugby	*Rugby* 2076 (2 *lines*)
The London Name Plate Manufacturing Co., Ltd.	Zylo Works, Marine View, Brighton, 7	*Brighton* 7025 (5 *lines*)

Magnesium Castings and Products Ltd.	89 Buckingham Avenue, Trading Estate, Slough	*Slough* 20207
Marston Excelsior Limited	Wolverhampton	*Wolverhampton* 21481
	49-59 Armley Road, Leeds, 12	*Armley* 38081-5
Messier Aircraft Equipment Limited	Liverpool Road, Warrington	*Warrington* 2244
Metalastik Limited	Evington Valley Road, Leicester	*Leicester* 25196
Miles Aircraft Limited	Reading, Berkshire	*Reading* 60811
Henry Miller & Company	"Skyhi" Works, Standard Road, Park Royal, London, N.W.10	*Willesden* 1302-3-4
Mollart Engineering Company Ltd.	Kingston By-Pass, Surbiton, Surrey	*Elmbridge* 3352-3-4 (3 *lines*)
The Mond Nickel Company Ltd.	Grosvenor House, Park Lane, London, W.1	*Grosvenor* 4131
Monochrome Limited	Studley Road, Redditch, Worcs.	*Studley* 121-2
Morrisons Engineering Ltd.	Purley Way, Croydon	*Croydon* 0191
D. Napier & Son Limited	Acton, London, W.3	*Shepherds Bush* 1220
Nitralloy Limited	47 Bank Street, Sheffield, 1	*Sheffield* 25907
The Palmer Tyre Ltd.	Herga House, Vincent Square, London, S.W.1	*Victoria* 8323 (6 *lines*)
Parnall Aircraft Limited	8 South Street, Park Lane, London, W.1	*Grosvenor* 2771-2
Percival Aircraft Limited	Luton Airport, Luton, Beds.	*Luton* 2960
Peto & Radford	Chequers Lane, Dagenham, Essex	*Rainham* 34
Philidas Limited	The Aerodrome, Reading, Berkshire	*Wargrave* 218
Photostat Limited	Adelaide House, King William Street, London, E.C.4	*Mansion House* 8226
Sir Isaac Pitman & Sons Limited	Parker Street, Kingsway, London, W.C.2	*Holborn* 9791 (4 *lines*)
Portsmouth Aviation, Limited	The Airport, Portsmouth	*Portsmouth* 74374
Pressed Steel Co. Ltd.	Cowley, Oxford	*Oxford* 77701
Pye Limited	Radio Works, Cambridge	*Cambridge* 3434
Ransomes, Sims & Jefferies Ltd.	Orwell Works, Ipswich	*Ipswich* 2201
Reynolds Tube Co. Ltd.	Hay Hall Works, Tyseley, Birmingham	*Acocks Green* 1607
R.F.D. Company Ltd.	Stoke Road, Guildford, Surrey	*Guildford* 3232
A. V. Roe & Company Limited	Newton Heath, Manchester	*Failsworth* 2020
Rolls-Royce Ltd.	Derby	*Derby* 2424
S. Grahame Ross Ltd.	Bath Road, Slough, Bucks.	*Burnham* 686-8
Rotol Limited	Cheltenham Road, Gloucester	*Gloucester* 4431
L. A. Rumbold & Co. Ltd.	Kingsgate Place, Kilburn, London, N.W.6	*Maida Vale* 7366-7-8
Sangamo Weston Ltd.	Great Cambridge Road, Enfield, Middlesex	*Enfield* 3434 and 1242
Saunders-Roe Ltd.	49 Parliament Street, Westminster, London, S.W.1	*Whitehall* 7271
Self-Priming Pump & Engineering Co., Ltd.	Edinburgh Avenue, Trading Estate, Slough, Bucks.	*Slough* 23277 (4 *lines*)
Serck Radiators Limited	Warwick Road, Birmingham, 11	*Victoria* 0531
Short Brothers (Rochester & Bedford) Ltd.	Rochester, Kent	

Simmonds Aerocessories Ltd.	Great West Road, Brentford, London	*Ealing* 2212 (18 *lines*)
Simms Motor Units Ltd.	Oak Lane, East Finchley, London, N.2	*Finchley* 2262
Smiths Aircraft Instruments Ltd.	Cricklewood Works, London, N.W.3	*Gladstone* 3333
The Sperry Gyroscope Co. Ltd.	Great West Road, Brentford, Middlesex	*Ealing* 6771 (10 *lines*)
M. E. Stace & Co. Ltd.	14 Portland Street, Cheltenham	*Cheltenham* 52021-2
Standard Telephones & Cables Ltd.	New Southgate, London, N.11	*Enterprise* 1234
Sterling Metals Ltd.	Northey Road, Foleshill, Coventry	*Coventry* 89031
Taylorcraft Aeroplanes (England) Ltd.	Britannia Works, Thurmaston, Leicester	*Syston* 86106-8
The Technological Institute of Great Britain	39 Temple Bar House, Fleet Street, London, E.C.4	*Central* 5940
Titanine Limited	Colindale, London, N.W.9	*Colindale* 8123 (6 *lines*)
Tubes Limited	Rocky Lane, Aston, Birmingham, 6	*Aston Cross* 3030
Ernest Turner Group Ernest Turner (London) Ltd. Ernest Turner (Weaving) Ltd. Ernest Turner Electrical Instruments Ltd. Chas. Dould & Son Ltd.	Northdown House, Northdown Street, King's Cross, London, N.1	*Terminus* 6674-5-6
Turner Manufacturing Co. Ltd.	Wulfruna Works, Moorfield Road, Wolverhampton	*Wolverhampton* 24456 (5 *lines*)
The United Steel Companies Limited	17 Westbourne Road, Sheffield, 10	*Sheffield* 60081 (7 *lines*)
Vickers-Armstrongs Limited (Aircraft Section)	Vickers House, Broadway, Westminster, London, S.W.1	*Abbey* 7777
Vokes Ltd.	Weybridge Works, Weybridge, Surrey Putney, S.W.15	*Byfleet* 240-243
Wadkin Ltd.	Green Lane Works, Leicester	*Leicester* 27114 (4 *lines*) 28021 (3 *lines*)
Warwick Aviation Company Ltd.	Warwick	*Warwick* 693
Westland Aircraft Limited	Yeovil	*Yeovil* 1100
Chas. Weston & Co. Ltd.	Torrington Avenue, Coventry	*Tilehill* 66291-2
A. C. Wickman Limited	Tile Hill, Coventry	*Tile Hill* 66271
Henry Wiggin & Company Ltd.	Wiggin Street, Birmingham	*Edgbaston* 2245
Wilkinson Rubber Linatex Ltd.	Frimley Road, Camberley, Surrey	*Camberley* 1595
Williamson Manufacturing Co. Ltd.	Litchfield Gardens, Willesden Green, London, N.W.10	*Willesden* 0073-0075
Worcester Windshields and Casements Ltd.	Barbourne, Worcester	*Worcester* 3326 (3 *lines*)
Yorkshire Engineering Supplies Ltd.	Bronze Foundries, Upper Wortley Road, Leeds, 12	*Leeds* 38234 *and* 38291
The Yorkshire Patent Steam Wagon Co.	Hunslet, Leeds, 10	*Leeds* 76551 (2 *lines*)

NATURE'S BONE-TO-MUSCLE WELD

Nature perfected the welding of muscle to bone: Metalastik perfected the rubber-to-metal weld.

When, on the 'bus, you arch your foot to prevent vibration jarring through your heels, Nature's construction softens the vibration: when a manufacturer is troubled by a vibrating piece of machinery he mounts it on Metalastik rubber mountings, or damps the oscillations of his crankshaft with a Metalastik torsional vibration damper.

In its campaign against vibration, Metalastik engineering safeguards feather-weight instruments, softens the harshness of high-powered engines, cushions the shudders in heavy torques, isolates the tremors of unbalanced machines and, in short, takes the 'Brr' out of vibration.

That engineering experience is at your disposal.

METALASTIK

Metalastik Ltd., Leicester.

Classics of the Applied Arts

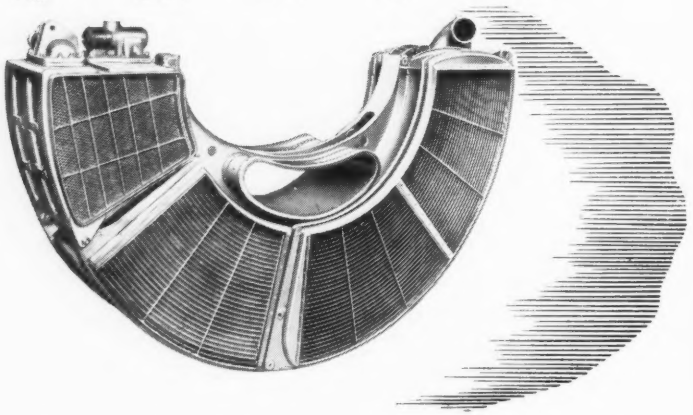
ANCIENT. THE STATUE OF ATHENE

The greatest of all Sculptures of the Parthenon, the Goddess Athene, stood 40ft. high. In her right hand was held a representation of Nike (Victory) while her left rested on the shield whose surface depicted the battle of the Greeks and the Amazons. The cost of the statue was fabulous, the flesh parts being of ivory and the draperies of pure gold.

MODERN

From the fashioning of rare and lovely materials in Ancient Greece, to the almost unlimited scope of modern metal fabrication, one great bond remains—Craftsmanship. Today it is used, not to commemorate War in fashioning the shape of its Goddess, but to achieve a lasting peace in the form of faultless aeronautical design and performance as typified by the products of The Serck Organisation.

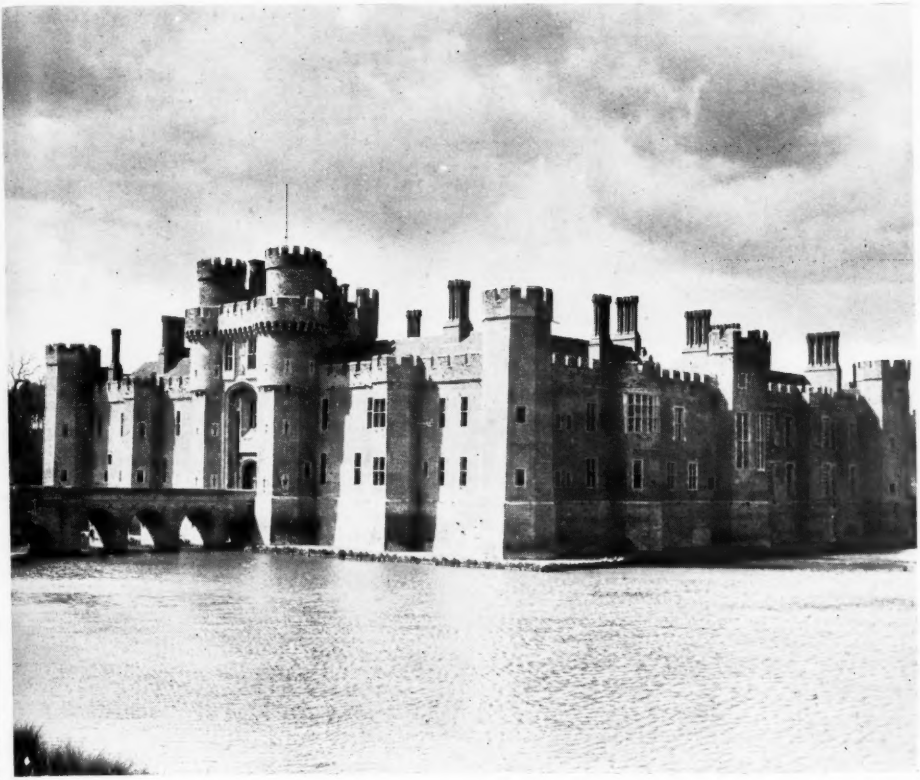
SERCK



RADIATORS & COOLERS FOR AIRCRAFT

SERCK RADIATORS LTD. - BIRMINGHAM, 11

Also at LONDON NEWCASTLE-ON-TYNE CHESTER SOUTHAMPTON MAIDSTONE SUDBURY BELFAST ETC.



In the best TRADITION . . .

. . . the name Churchill has since the year 1865 been in the forefront of machine tool manufacture and distribution, supplying a wide range of the highest quality products.

You should consult the Churchill organisation before deciding your future requirements. Application of their abundant knowledge of machine tools and equipment to your particular problems may mean much to you.

CHURCHILL

Machine Tools & Equipment

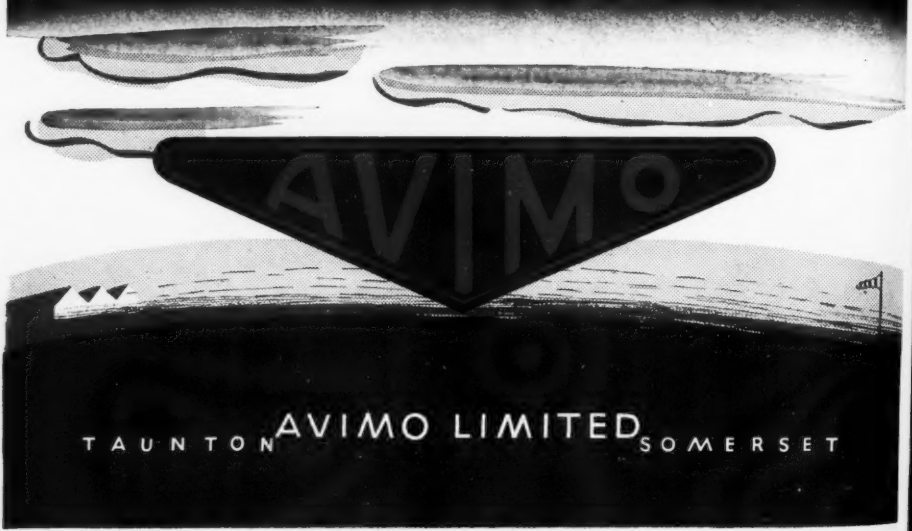
CHURCHILL-FAY AUTOMATIC LATHES . CHURCHILL GRINDING MACHINES . CINCINNATI MILLING MACHINES . CINCINNATI GRINDING MACHINES CINCINNATI BROACHING MACHINES . CHURCHILL-REDMAN SHAPERS AND LATHES . PETERMANN AUTOMATICS CONOMATICS CLEVELAND RIGID HOBBERS . JONES & LAMSON TURRET LATHES JONES & LAMSON THREADGRINDERS . NATCO MULTIPLE SPINDLE DRILLING AND BORING MACHINES RED RING GEAR SHAVING AND LAPPING MACHINES . RED RING GEAR CHECKING MACHINES

CHARLES CHURCHILL & CO. LTD., COVENTRY ROAD, SOUTH YARDLEY, BIRMINGHAM
CHURCHILL-REDMAN LTD. HALIFAX • V. L. CHURCHILL & CO. LTD., WORCESTER

Progress by Quality

TODAY IS TOMORROW

Today's experience is tomorrow's gain and in the 'Morrow' the post-war design and manufacture of Avimo Optical - Mechanical - Electrical Instruments and Aircraft Equipment will incorporate all the tremendous wartime developments.

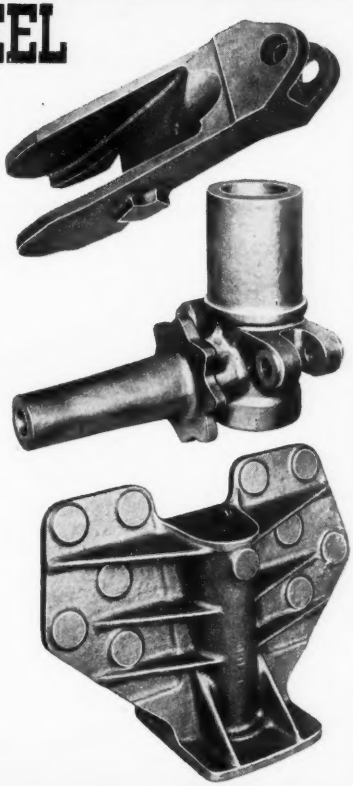


TAUNTON AVIMO LIMITED SOMERSET

APPROVED UNDER AIR NAVIGATION RULES FOR CIVIL AVIATION

DAVID BROWN CENTRIFUGAL CASTINGS FOR AIRCRAFT

IN HIGH TENSILE STEEL



. . . . present designers with freedom for creating new ideas in irregular and complex types of steel castings having fatigue and ductility properties comparable with forged steel.

Representing the highest level of attainment in steel foundry technique and metallurgical science, DAVID BROWN STEEL CASTINGS for AIRCRAFT now meet a special requirement of the industry.

Draft specification D.T.D. 666 covering alloy steel castings for Aircraft is available.

DAVID BROWN
& SONS (HUDDERSFIELD) LIMITED
PENISTONE WORKS
PENISTONE NEAR SHEFFIELD

Printed by the Lewes Press (Wightman & Co., Ltd.), Friars Walk, Lewes, England, and Published by the Royal Aeronautical Society, 4, Hamilton Place, London, W.1, England.